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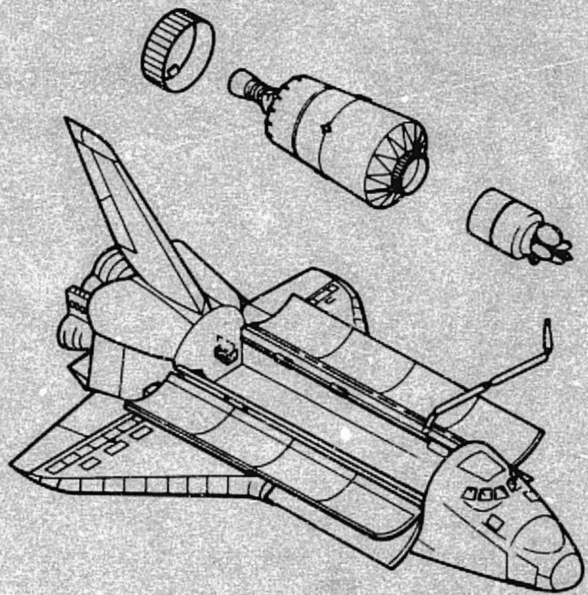

SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME II • TUG/PAYLOAD/ORBITER INTERFACE ANALYSES

GENERAL DYNAMICS
Convair Division

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SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME II ✦ TUG/PAYLOAD/ORBITER INTERFACE ANALYSES

June 1975

Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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FOREWORD

The study described in this report was conducted by Convair Division of General Dynamics Corporation under NASA Contract NAS8-31012. The work was under the management of the NASA Marshall Space Flight Center, Tug Task Team, in conjunction with four complementary Tug-related study efforts.

The study was conducted between July 1974 and March 1975.

ACKNOWLEDGMENTS

Due to the broad scope of the interface compatibility study, many individuals were involved in providing technical assistance. General Dynamics Convair personnel who significantly contributed to the study include:

Ed Bock — Study Manager

Lee Browning — Structures/Dynamics

Jack Dyer
Wes Dreyer
Lee Siden

Jerry Nuding — Mechanisms

Joe Streetman — Fluids

Bob Eidson

Al Walburn — Environmental

Gordon Stone
Gordon Getline

Jack Fisher — Avionics

Wayne Groesbeck
Stan Maki
Bob Horsley

Norm Tipton — Safety

Bob Howe

Lee Bolt — Economic Analysis

Tom Tindel

Dick Parsons — Operations

Ken Nuss

Frank Jarlett — Programmatics

Ed Seiden
Carl Crone

NASA technical direction for the interface study was by:

Edward Stluka — Contracting officer's representative (COR)
Ralph Barnes — Assistant COR

SUMMARY

The Space Tug/Shuttle interface compatibility study was performed to identify, evaluate, and develop Tug plus payload-to-Orbiter accommodations requirements. The study was the instrument through which design changes to satisfy these requirements were submitted to NASA.

Previously performed Tug-related studies did not specifically address the use or suitability of Orbiter-supplied general-purpose payload support equipment or provide detail description of any Tug-dedicated peripheral equipment. The interface study investigated these areas and supplied the lacking data.

Shuttle interfaces required for Space Tug accommodations are primarily involved with supporting and servicing the Tug during launch countdown, flight, and post landing; deploying and retrieving the Tug on orbit; and maintaining control over the Tug when it is in or near the Orbiter. Each of these interface areas was investigated during the study to determine the best physical and operational method of accomplishing the required functions, with an overriding goal of establishing simple and flexible Orbiter interface requirements suitable for Tug, Tug payloads, IUS and other cargo.

The Space Tug/Shuttle interface compatibility study was arranged into six tasks that were accomplished sequentially within the eight-month performance period. The study was managed by the Tug Task Team at NASA's Marshall Space Flight Center, along with four other Tug-related contracted activities. These other studies, involving ground and flight operations, payload/Tug interfaces, and Tug avionics, supported the interface study by generating accommodation requirements within their respective study areas.

A systematic approach was used to ensure that no interface function was missed or ignored. This approach 1) defined functional requirements derived during Tug/Orbiter operations as they related to determining interface needs, and 2) organized these functional interface requirements to permit systematic evaluation within technical disciplines. Major elements of this approach were: use of operational functional flow diagrams to identify all interface requirements, a safety and reliability assessment of identified operations and interface requirements, and a suitably organized compilation of these interface requirements.

Using these functional requirements, each interface subsystem was evaluated to develop the best implementation technique, and an interface system concept was assembled.

The recommended system concept for supporting and deploying Tug from Orbiter employs a cylindrical load-carrying structure called a deployment adapter. The deployment adapter contains all Tug-peculiar mechanisms required for transfer of Orbiter/ground services and support of deployment, retrieval, and abort operations. Because the deployment adapter is a cylindrical structure to provide efficient axial load distribution, a rotational deployment feature is incorporated to allow Tug removal during deployment without infringing on the Orbiter cargo bay volume available for Tug payloads. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into the Orbiter. The entire Tug, adapter, and umbilical support is installed as an autonomous unit into the Orbiter.

Detail description of deployment adapter and other Tug-peculiar peripheral equipment (crew compartment interface panels and cargo bay electrical umbilical kits) were provided as study output. In addition to peripheral equipment definition, use of Orbiter-supplied equipment was investigated.

An evaluation of documented Orbiter payload services (JSC 07700, Vol. XIV, Rev, C) indicated that some changes would be desirable for Tug plus its payloads. Twenty-two proposed changes to this document were prepared by the Space Tug/Shuttle Interface Compatibility Study Team and submitted to MSFC for their assessment and processing. These proposed changes covered detail requirements for Tug service umbilicals, RMS control capability, Orbiter dump/vent provisions, structural attachments, and improved Tug accessability to Orbiter-supplied avionics equipment.

As a final study result, interface areas that would benefit from further technical analyses and predevelopment work have been identified. This suggested additional effort includes structural dynamic response analyses and software design and demonstration in areas of RMS deployment/retrieval control, Tug plus deployment adapter monitor and control, and caution and warning implementation.

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SECTION 1

INTRODUCTION

The Space Transportation System flight vehicle, the Space Shuttle, consists of the major segments shown in Figure 1-1. Included as part of this transportation system is a proplusion stage called the Space Tug, depicted in Figure 1-2,which is carried into low-earth orbit by the Space Shuttle in the Orbiter cargo bay. The Tug extends Shuttle capability by placing payloads into higher orbits, such as geosynchronous and interplanetary trajectories,so that more payload users may be accommodated.

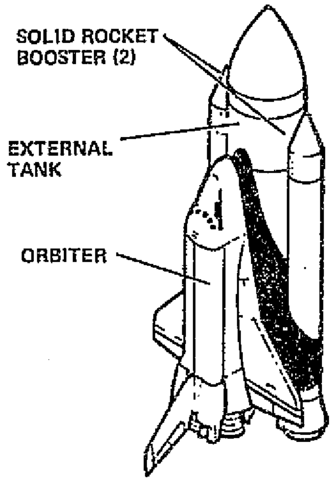

Figure 1-1. Space Shuttle Configuration

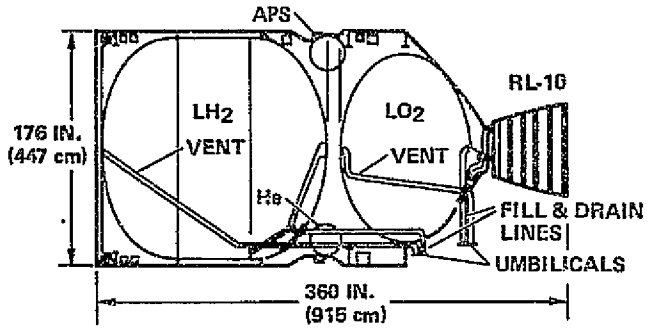

Figure 1-2. MSFC Baseline Tug

1.1 STUDY BACKGROUND AND OBJECTIVES

Current resource constraints preclude simultaneous development of both Space Shuttle and Tug. The government plans to have the Air Force develop an interim upper stage (IUS), to be followed by a NASA-developed full capability Tug at a later date. The IUS is planned to be operational at or near the Shuttle's initial operational capability (IOC). Although the Space Tug operational date is planned for 1983, it is important that Shuttle/Tug interface requirements will be identified early so that they can be incorporated into the Shuttle. This will prevent having to constrain the Tug design due to prior Shuttle development. This advanced planning will also avoid major and costly Shuttle modification when Tug is introduced.

The Space Tug/Shuttle Interface Compatibility Study was structured to compile, screen, evaluate, and recommend suitable Orbiter interface provisions for Space Tug integration.

The Shuttle/Orbiter, as currently configured, includes some general payload accommodations applicable for Space Tug, but a detailed investigation of specific interface requirements had not previously been undertaken. Tug interface requirements needed immediate definition and consideration in conjunction with other payload interface

requirements for incorporation into the Shuttle Orbiter at the earliest possible date. Tug/Shuttle interface compatibility achieved early during Shuttle development will result in lower Space Transportation System program costs.

The purpose of the Space Tug/Shuttle Interface Compatibility Study was to provide timely detailed identification of Tug-related interface requirements, and to act as the instrument by which design changes to satisfy these requirements were submitted to NASA. Figure 3-1 identifies the typical Tug-related Orbiter interfaces for the MSFC baseline cryogenic Tug.

The Interface Study was managed by the Tug Task Team at NASA's Marshall Space Flight Center, along with four other parallel Tug-related contracted activities. These other studies, involving ground and flight operations, payload/Tug interfaces, and Tug avionics, supported the Interface Study by generating accommodation requirements within their respective study areas.

1.2 FINAL REPORT ORGANIZATION

The results of the Space Tug/Shuttle Interface Compatibility Study are contained in the four volumes of the final report. The four volumes are organized as follows:

Volume I Executive Summary — Contains in summary form the objectives, relationship of the Interface Study to other NASA efforts, approach,

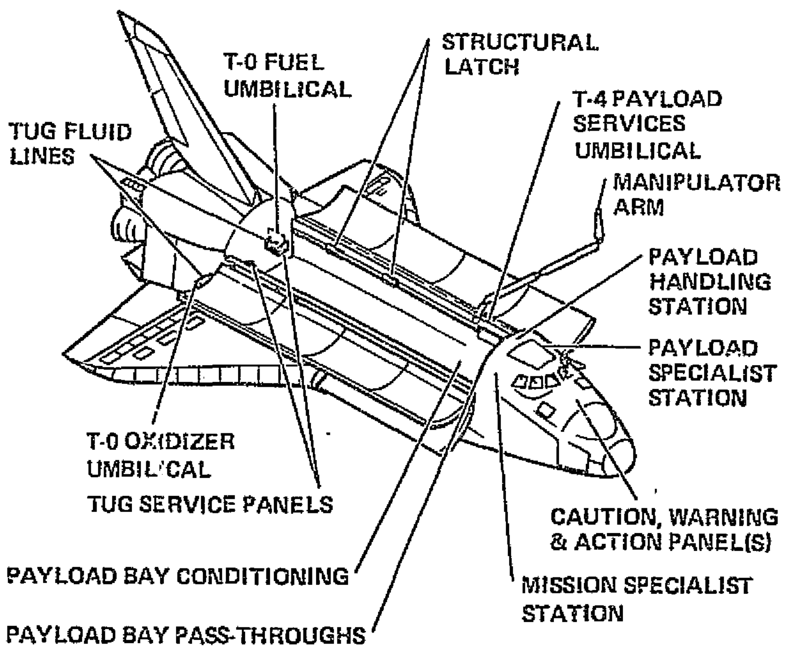

Figure 1-3. Tug-Related Orbiter Interface Provisions

data generated and significant results, limitations, research implications, and recommendations for additional effort made as a result of the study.

Volume II Tug/Payload/Orbiter Interface Analysis — Includes the subsystem technical analysis performed, including the definition of the Tug functional interface requirements and payload service requirements, detailed analyses and trade studies of Tug/Orbiter interfaces, appropriate sensitivity studies, and special emphasis tasks.

Volume III Tug/Payload/Orbiter Interface Requirement — Contains the system level interface assessment and the operation/physical definition of the recommended Tug/Orbiter interface, plus a description of the Orbiter and baseline Tug changes needed to accommodate the recommended interface. It also includes a comparison of IUS and Tug interface requirements, and recommends interface simulation-demonstration candidates.

Volume IV Cost Analysis — Provides the detailed study economic analysis approach, methodology, and results.

The study was arranged into six tasks, which were accomplished sequentially within the eight-month performance period:

Task 1 - Functional Interface Requirements Definition. Tug ground and flight operations were analyzed to obtain a complete accounting of all potential Tug/Orbiter interfaces, their related operations, and safety functional requirements. This analysis was conducted using baseline vehicle and operations definitions supplied by NASA-MSFC at the start of the study effort.

Task 2 - Baseline Tug Interface Analyses. Approved functional interface requirements were systematically evaluated to obtain alternative solutions and determine the optimum interface approach to satisfy each baseline Tug need. Specific payload through Tug and direct to Orbiter service requirements obtained by trade study were included. From these subsystem investigations and trade studies, detailed interface requirements for Tug/Shuttle compatibility were itemized.

Task 3 - Sensitivity Analysis. Using updated subsystem requirements from Task 2, sensitivity analyses were performed to evaluate the effect of Tug operations and design changes on Tug/Orbiter interface requirements.

Task 4 - Tug/Orbiter Interface Requirements. Results from baseline Tug interface analyses (Task 2) were assembled through a total Tug systems interface concept trade study, and a composite set of preliminary Tug/payload/Orbiter interface requirements were submitted for NASA evaluation. These proposed Orbiter accommodation revisions were submitted as recommended Level II changes. The NASA assessment included requirements reviews by MSFC and the Shuttle project.

Task 5 - Interface and Baseline Revisions. Revised interface requirements were prepared in areas where the government disapproved the initial requirements. Revisions

were defined through trade studies of alternative approaches and baseline Tug changes. Since relatively few proposed changes were rejected, unused resources were applied to Tug/Orbiter interface related special emphasis tasks.

Task 6 - IUS/Tug Interface Comparison. Approved Tug requirements from Tasks 4 and 5 were compared with similar IUS requirements. Interface requirement incompatibilities were evaluated to identify and define major problems and recommend compromise solutions.

1.3 VOLUME II ORGANIZATION

The Tug/payload/Orbiter interface analyses, contained in this volume of the final report, consists of work performed under Study Tasks 1, 2, and 3. Specifically, it contains the data and information required to satisfy the four study objectives listed below.

a. Assurance that no Tug to Orbiter functional interfaces (hardware or procedural) are missed or ignored. This objective was addressed in Study Task 1 (Section 2), where all functional interface requirements were derived and categorized by operational sequence and subsystem.

b. Allocation of Tug payload services and their associated interface requirements either as through Tug to Orbiter or directly from payload to Orbiter. The payload/Orbiter services accommodations trade study, performed under Study Task 2 (Section 3) assembled all identified tug payload service requirements, established recommended support levels, and allocated service routings. The results of this trade study, combined with Tug requirements delineated in Task 1, gave complete visibility to all combined Tug-plus-payload functional interface requirements.

c. Evaluation of alternative techniques for implementing the Tug and payload functional, safety, and service interface requirements. These subsystem interface analyses and trade studies were performed as the major effort of Task 2 as well as special emphasis studies within Task 5. Documentation of this work is contained in Section 4.

d. Determine interface requirements impacts associated with potential baseline Tug vehicle changes. This objective was addressed in Study Task 3 (Section 5) where sensitivities of recommended interface solutions were investigated for the effect of baseline Tug configuration/design revisions.

SECTION 2

BASELINE TUG FUNCTIONAL INTERFACE REQUIREMENTS DEFINITION

Fundamental to a study of Tug interface requirements is the assurance that no interface function has been overlooked or ignored. Thus a systematic approach was used to identify and document, in this section, all interface requirements encountered during Tug/Orbiter operations. This approach, illustrated in Figure 2-1, defined functional requirements derived during Tug/Orbiter operations as they relate to determining interface needs and organized these functional interface requirements to permit systematic evaluation within technical disciplimes. Major elements of this approach are: 1) use of operational functional flow diagrams to identify all interface requirements, 2) a safety and reliability assessment of identified operations and interface requirements, and 3) a suitably organized compilation of these interface requirements.

a. Operations Functional Flows and Interface Requirements. The first step in the Task 1 analytical approach was to develop, or modify, Space Tug ground and flight operations function flow diagrams. The top level flow diagram and all ground operations first-level flow diagrams were based on those in the Baseline Space Tug Ground Operations (MSFC 68M00039-4) document. The top-level flow provided in that source was modified to include flight mission functions that involve Tug/Orbiter interfaces. The resulting modified or derived function flow diagrams used in this task are presented in Section 2.1 together with their associated operationally phased functional interface requirements data sheets.

b. Safety and Reliability Requirements. A systematic evaluation of Tug/Orbiter interface requirements in terms of interface safety was performed. The functional flow diagrams and the associated functional interface requirements were

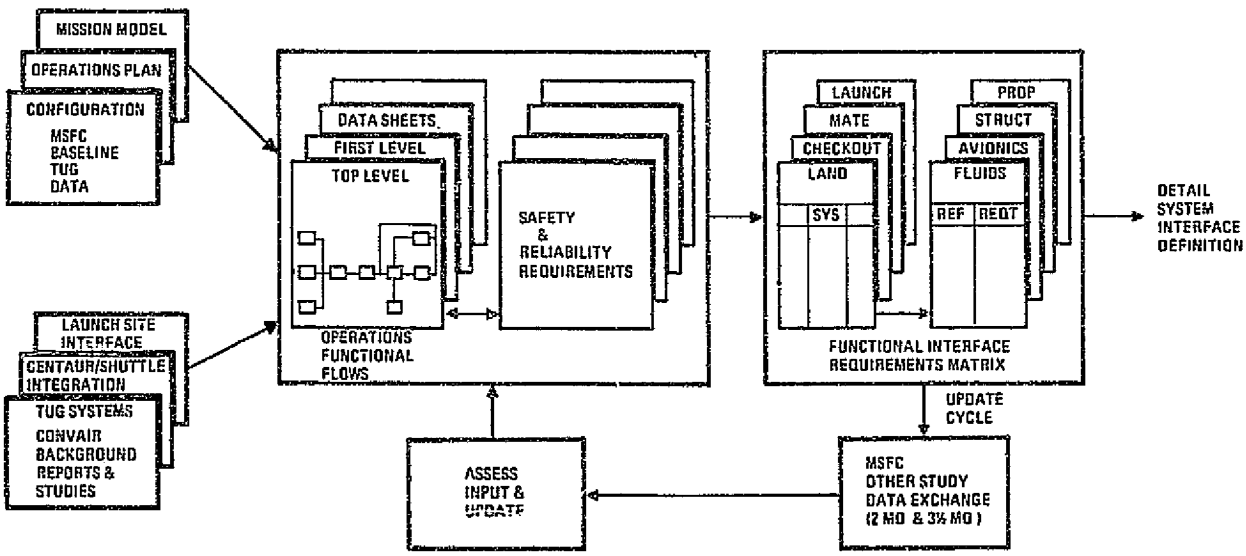

Figure 2-1. Functional Interface Requirements Definition Approach

used as the basis in performing the safety analysis. A hazard analysis was performed for each of the functional interfaces identified. The controls/design constraints/operations constraints required to counteract each of the potential hazards were then identified. Safety requirements are compiled in Section 2.2.

c. System Functional Interface Requirements. Requirements from a. and b. above were arranged by subsystem or technical discipline to better support the Task 2 trade studies. This tabulation, in conjunction with the operationally phased tabulation obtained in a. provided a complete data matrix listing all Tug/Orbiter functional interface requirements generated during a complete Tug/Orbiter operations cycle. In Section 2.3 these functional interface requirements are collated by Tug system or Tug/Orbiter procedural interface and augmented by the addition of safety/reliability criteria.

The functional interface requirements data contained here were initially documented in report CASD/LVP 74-048-FIRM. This compilation of Tug functional requirements was published early in the study for use by the interface study and the parallel MSFC Tug studies, to ensure that the detail implementation of Tug/Orbiter interfaces satisfied all safety and functional needs. This Functional Interface Requirements Matrix is republished in its entirity in tne following sections.

2.1 MISSION PHASED FUNCTIONAL INTERFACE REQUIREMENTS

The first step in the functional interface requirements definition analytical approach was to develop, or modify, Space Tug ground and flight operations function flow diagrams. The top level flow diagram shown in Figure 2-2, and all ground operations first level flow diagrams, are based on those in the Baseline Space Tug Ground Operations (MSFC 68M00039-4) document. The top level flow provided in that source has been modified to include flight mission functions that involve Tug/Orbiter interfaces, as shown in Figure 2-2 (blocks 11.0 through 14.0).

All flight mission functions used in this study were developed by Convair based on information in the Baseline Space Tug Flight Operations (MSFC 68M00039-3), Baseline Space Tug System Requirements and Guidelines (MSFC 68M00039-1), Space Shuttle System Payload Accommodations (JSC 07700, Vol. XIV), and Tug Operations and Payload Support Study (Vol. 3, Part 1; Contract NAS8-28876 Final Report) documents. All function flow diagrams used in the study are included in this section.

The Tug/Orbiter operations cycle sequence used in the functional interface requirements tabulations is:

Block 5.0 Postlanding Operations
Block 2.0 Tug/Spacecraft/Orbiter Mate and Checkout
Block 1.0 Launch Operations
Block 11.0 Flight Mission-Ascent Phase
Block 12.0 Flight Mission-Tug/Spacecraft Retrieval & Landing
Block 13.0 Flight Mission-Abort Termination

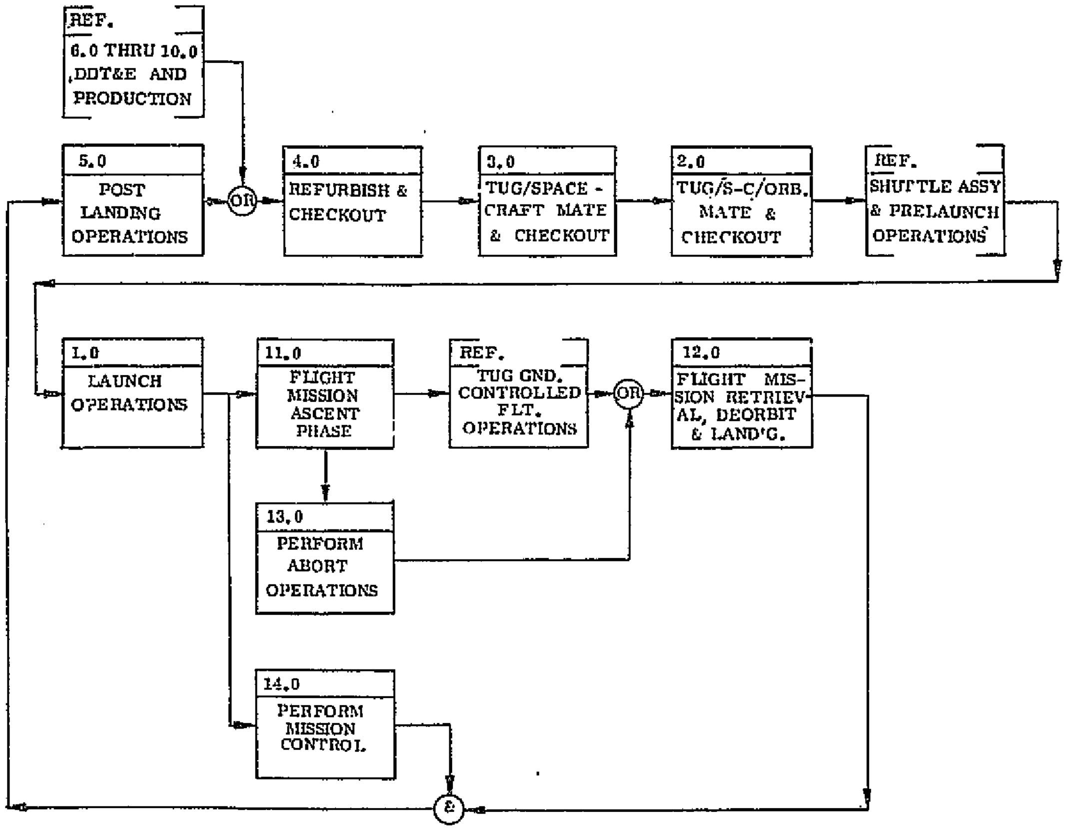

Figure 2-2. Space Tug Ground and Flight Operations

Blocks 6.0 through 10.0, the DDT&E and Production functions, do not involve Tug/Orbiter interfaces and are not further considered in this study. Similarly, Blocks 3.0 and 4.0, the Tug refurbishment, checkout and Tug/spacecraft mating functions do not involve any Tug/Orbiter interfaces and are not further considered in this study.

Within this operational cycle, the Space Tug/Shuttle Interface Compatibility Study encompasses all operational, procedural and hardware interfaces, both physical and RF, that occur between the Tug and Orbiter during joint operations. This initial identification of Tug/Orbiter interface functional requirements is organized in a typical operational mission sequence beginning with Tug/Orbiter landing, through ground turnaround, launch, and subsequent flight mission. The following sections present the first-level function flow diagram and its associated functional interface requirements data sheets for each major block of activities in the operational cycle that involve joint Tug/Orbiter operations.

2.1.1 POST LANDING OPERATIONS. The first-level post landing operations function flow diagram is shown in Figure 2-3. This flow corresponds to Exhibit 3-8 in Reference 1 and is modified to include additional functions associated with special post landing operations following flight mission abort terminations (Blocks 5.1A-RTLS and 5.1A-AOA/ATO). Related functional interface requirements data sheets follow the flow diagram. No data sheets are included for Block 5.4 and 5.5 since there are no Tug/Orbiter interfaces during these activities.

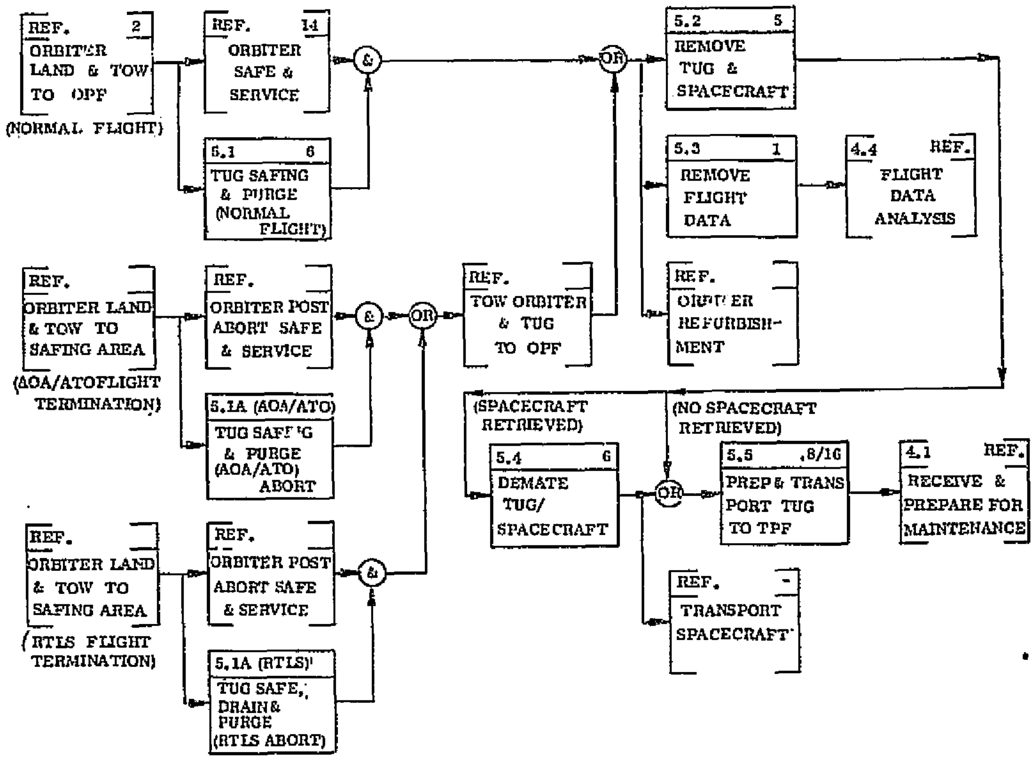

Figure 2-3. Space Tug Post Landing Operations; Block 5.0, First-Level Functional Flow

FUNCTION FLOW BLOCK NO. 5.1	FUNCTION TITLE: Tug Safing & Purging	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter (M) Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.1.1 Following Orbiter landing, tow to safing area.	Structure	Provide attach/support fittings compatible with Orbiter payload support locations, interface surface details and loads. Provide load-carrying deployment adapter.
5.1.2 Verify power & purge gas availability, set all controls to safe position.	Structure	Same as 5.1.1
	Avionics	Provide instrumentation & data management capability to display power & purge gas data at payload/mission specialists station.
	Procedural	Provide instructions in payload/mission specialists check list to accomplish this task.
5.1.3 Flight crew egress, ground crew ingress.	Structure	Same as 5.1.1
5.1.4 Verify propellant tank pressure-vent cycling.	Structure	Same as 5.1.1
	Avionics	Provide instrumentation & data management capability to display pressure/vent data at payload/mission specialists station.
	Fluid	Provide hydrogen/oxygen vent connection to overboard vent ports.
	Procedural	Provide instructions in ground crew checklist to accomplish this task.
5.1.5 Verify insulation purging.	Structure	Same as 5.1.1
	Avionics	Provide instrumentation & data management capability to display purge operation data at the payload/mission specialist station.
	Fluids	Provide overboard dump line connection.
	Procedural	Provide instructions in ground crew checklist to accomplish this task.

Rev.

FUNCTION FLOW BLOCK NO. 5.1	FUNCTION TITLE: Tug Safing & Purging	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.1.6 Continue purging until systems are safe.	Structure	Same as 5.1.1
	Avionics	Same as 5.1.5
	Fluids	Same as 5.1.5
	Procedural	Provide instructions in ground crew checklist to monitor purge operation.
5.1.7 Move Orbiter to OPF.	Structure	Same as 5.1.1. Must be adequate to support Tug during horizontal orbiter tow from landing/safety area to OPF. Must accommodate transit induced loads.

Rev.

FUNCTION FLOW BLOCK NO. 5.1A (RTLS)	FUNCTION TITLE: Tug Safing & Purge	
	CONFIGURATION: Post-RTLS-Abort	Sheet 1 of 3

INTERFACE:

MPA Tug-Orbiter | ___ Tug-Payload | ___ Tug-Payload-Orbiter

PA Tug-GSE | ___ Tug-Facility

M = Mechanical Handling | P = Propellant/Pressurant/Fluid | A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.1.1A (RTLS) Following Orbiter landing rollout, tow to Safing Area.	Structure	Provide attach/support fittings to mate with Orbiter payload support fittings and/or payload deployment adapter.
5.1.2A (RTLS) Verify tank condition, fluid levels, power & set controls to safe condition. (Accomplish during rollout or tow)	Structure	Same as 5.1.1A (RTLS)
	Avionics	Provide instrumentation & data management capability to display required data at payload/mission specialist station. (Implies hardline interface between Tug and Orbiter via aft bulkhead interface panels.)
	Environment	Provide payload bay air conditioning purge following Orbiter landing.
	Procedural	Provide instructions in payload/mission specialist checklist to accomplish this task.
5.1.3A (RTLS) Flight crew egress, ground crew ingress.	Structures	Same as 5.1.1A (RTLS).
5.1.4A (RTLS) Position and connect propellant vent & reactant drain equipment.	Structures	Same as 5.1.1A (RTLS).
	Avionics	Same as 5.1.2A (RTLS).
	Fluids	Provide reactant drain & propellant vent interface panels at Orbiter mold line & thru aft bulkhead panel to Tug.
	Procedural	Provide input to Orbiter ground operations checklist to accomplish or support this task.
5.1.5A (RTLS) Drain ACPS propellant	Structure	Same as 5.1.1A (RTLS).
	Avionics	Provide instrumentation & data management capability to display required data at payload/mission specialist stations & to control propellant drain from there. (Implies hardline interface between Tug & Orbiter via aft bulkhead panels). (May require ground power interface.)

Rev. A

FUNCTION FLOW BLOCK NO. 5. 1A (RTLS)	FUNCTION TITLE: Tug Safing & Purging	
	CONFIGURATION: Post-RTLS-Abort	Sheet 2 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5. 1. 5A (RTLS) Cont'd	Fluids	Provide ACPS propellant drain interface panels at Orbiter mold line & via aft bulkhead to permit Tug fluid drain in horizontal attitude. (Requires low point drain line connection & routing.)
	Procedural	Same as 5. 1. 4A (RTLS).
5. 1. 6A (RTLS) Disconnect drain equipment.	Structure	Same as 5. 1. 1A (RTLS).
	Fluids	Same as 5. 1. 4A (RTLS).
	Procedural	Same as 5. 1. 4A (RTLS).
5. 1. 7A (RTLS) Connect purge equipment.	Structure	Same as 5. 1. 1A (RTLS).
	Avionics	Same as 5. 1. 2A (RTLS).
	Fluids	Provide ACPS & main propellant tank purge interface connectors on Orbiter mold line & thru aft bulkhead panel to Tug.
	Procedural	Same as 5. 1. 4A (RTLS).
5. 1. 8A (RTLS) Purge LO_2 & LH_2 tanks to acceptable concentration level.	Structure	Same as 5. 1. 1A (RTLS).
	Avionics	Provide instrumentation & data management capability to display required data at payload/mission specialists stations & to control tank purge from there. (Implies hardline interface between Tug & Orbiter via aft bulkhead panels & lines to Orbiter crew compartment.) (May require ground power interface.)
	Fluids	Provide main LO_2 & LH_2 interface panels at Orbiter mold line & via aft bulkhead to permit tank purge.
	Procedural	Same as 5. 1. 4A (RTLS)
5. 1. 9A (RTLS) Purge ACPS propellant storage tank to acceptable concentration level.	Structure	Same as 5. 1. 1A (RTLS).
	Avionics	Same as 5. 1. 8A (RTLS).
	Fluid	Same as 5. 1. 8A (RTLS) except for ACPS tank.

Rev. A

FUNCTION FLOW BLOCK NO. 5. 1. A (RTLS)	FUNCTION TITLE: Tug Safing & Purging	
	CONFIGURATION: Post-RTLS-Abort	Sheet 3 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5. 1. 9A (RTLS) Cont'd	Procedural	Same as 5. 1. 4A (RTLS).
5. 1. 10A (RTLS) Disconnect purge equipment.	Structures, Avionics, Fluids & Procedural	Same as 5. 1. 7A (RTLS) for all systems.
5. 1. 11A (RTLS) Move Orbiter to OPF.	Structure	Same as 5. 1. 1A (RTLS) plus adequate latches or restraints to react loads imposed by Orbiter horizontal tow.

Rev.

FUNCTION FLOW BLOCK NO. 5.1A (AOA/ATO)	FUNCTION TITLE: Tug Safing & Purge	
	CONFIGURATION: Post AOA/ATO Abort	Sheet 1 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.1.1A (AOA/ATO) Following Orbiter landing rollout, tow to Safing Area.	Structure	Provide attach/support fittings to mate with Orbiter payload support fittings and/or payload deployment adapter.
5.1.2A (AOA/ATO) Verify tank condition and power available & set controls to safe condition. (Accomplish during rollout or tow.)	Structure Avionics	Same as 5.1.1A (AOA/ATO) Provide instrumentation & data management capability to display required data at payload/mission specialist station. (Implies hardline interface between Tug & Orbiter via aft bulkhead interface panels.)
	Environment	Provide payload bay air conditioning purge following Orbiter landing.
	Procedural	Provide instructions in payload/mission specialist checklist to accomplish this task.
5.1.3A (AOA/ATO) Flight crew egress, ground crew ingress.	Structure	Same as 5.1.1A (AOA/ATO).
5.1.4A (AOA/ATO) Position and connect ACPS propellant drain equipment.	Structures Avionics Fluids	Same as 5.1.1A (AOA/ATO). Same as 5.1.2A (AOA/ATO). Provide reactant drain & propellant vent interface panels at Orbiter mold line & thru aft bulkhead panel to Tug.
	Procedural	Provide input to Orbiter ground operations checklist to accomplish or support this task.
5.1.5A (AOA/ATO) Drain the ACPS propellant tanks.	Structure Avionics	Same as 5.1.1A (AOA/ATO). Provide instrumentation & data management capability to display required data at payload/mission specialist stations & to control propellant drain from there. (Implies hardline interface between Tug and Orbiter via aft bulkhead panels.) (May require ground power interface.)

Rev. A

FUNCTION FLOW BLOCK NO.	FUNCTION TITLE: Tug Safing & Purging	
5. 1A (AOA/ATO)	CONFIGURATION: Post AOA/ATO Abort	Sheet 2 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5. 1. 5A (AOA/ATO) Cont'd	Fluids	Provide ACPS propellant drain interface panels at Orbiter mold line & via aft bulkhead to permit Tug fluid drain in horizontal attitude. (Requires low point drain line connection & routing.)
	Procedural	Same as 5. 1. 4A (AOA/ATO).
5. 1. 6A (AOA/ATO) Disconnect drain equipment.	Structure	Same as 5. 1. 1A (AOA/ATO).
	Fluids	Same as 5. 1. 4A (AOA/ATO).
	Procedural	Same as 5. 1. 4A (AOA/ATO).
5. 1. 7A (AOA/ATO) Connect purge equipment.	Structure	Same as 5. 1. 1A (AOA/ATO).
	Avionics	Same as 5. 1. 2A (AOA/ATO).
	Fluids	Provide ACPS & propellant tank purge interface connectors on Orbiter mold line & thru aft bulkhead panel to Tug.
	Procedural	Same as 5. 1. 4A (AOA/ATO).
5. 1. 8A (AOA/ATO) Purge ACPS propellant storage tank & main propellant tanks.	Structure	Same as 5. 1. 1A (AOA/ATO).
	Avionics	Provide instrumentation & data management capability to display required data at payload/mission specialists station to control tank purge from there. (Implies hardline interface between Tug & Orbiter via aft bulkhead panels & lines to Orbiter crew compartment.) (May require ground power interface.)
	Fluids	Provide ACPS propellant and main propellant tank purge interface panels and lines at Orbiter mold line & thru aft bulkhead to permit tank purge.
	Procedural	Same as 5. 1. 4A (AOA/ATO).
5. 1. 9A (AOA/ATO) Disconnect purge equipment.	Structures, Avionics, Fluids & Procedural	Same as 5. 1. 7A (AOA/ATO) for all systems.

Rev. A

FUNCTION FLOW BLOCK NO.	FUNCTION TITLE: Tug Safing & Purging	
5.1A (AOA/ATO)	CONFIGURATION: Post AOA/ATO Abort	Sheet 3 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.1.10A (AOA/ATO) Move Orbiter to OPF.	Structures	Same as 5.1.1A (AOA/ATO) plus adequate latches or restraints to react loads imposed by Orbiter horizontal tow.

Rev.

FUNCTION FLOW BLOCK NO. 5.2	FUNCTION TITLE: Remove Tug/Spacecraft	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

M Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.2.1 Install Orbiter work stands & open Orbiter cargo bay doors.	Structure	Provide attach/support fittings to mate with Orbiter payload support fittings and/or payload deployment adapter.
	Avionics	Provide instrumentation & data management capability to monitor tank and insulation condition at payload/mission specialists station during this task.
	Procedural	Provide instructions in ground crew checklist to accomplish condition monitor during this task.
5.2.2 Install cargo bay workstands & attach handling equipment to Tug.	Structure	Same as 5.2.1 plus provide attach points for handling equipment to lift Tug (& Spacecraft) clear of Orbiter and which are compatible with Orbiter installation & clearance requirements.
	Procedural	Provide instructions in Orbiter ground crew operations checklist to accomplish/assist with this task.
5.2.3 Disconnect Tug & adapter interfaces from Orbiter.	Structure	Same as 5.2.2.
	Avionics	Provide Avionics interface disconnect panel/receptacles for all Tug/Shuttle avionics interface connections.
	Fluids	Provide fluids interface disconnect panel(s) receptacles for all Tug/Shuttle fluid interface connections.
	Procedural	Same as 5.2.2.
5.2.4 Lift Tug/deployment adapter/spacecraft from cargo bay & install on pallet/transporter.	Structures	Same as 5.2.2.
	Procedural	Same as 5.2.2.
5.2.5 Install Tug workstands.		No Tug/Shuttle interface.
5.2.6 Remove Tug handling gear.		No Tug/Shuttle interface.

Rev. A

FUNCTION FLOW BLOCK NO. 5.3	FUNCTION TITLE: Remove Flight Data	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

M-A Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

M Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
5.3.1 Remove flight data from Orbiter: CAUTION: Orbiter/Tug safing operations must be completed and/or clearance obtained from the Safety Engineer.	Avionics	Provide interface to store data at payload/mission specialists station during joint Tug-Shuttle flight phases of mission
Note: Flight data storage will probably use a mag-bubble or CCD device. Thus, there will be no tapes to physically remove, but rather an avionics interface plug to dump the data electronically to a ground station.	Procedural	Provide instructions in Orbiter ground crew operations checklists to assist with and/or provide access to accomplish this task.
5.3.2 Remove flight data tapes from Tug. Note: Accomplish when access is available following Tug removal from payload bay.		No Tug-Orbiter interface involved when accomplished following Tug removal.

Rev.

2.1.2 TUG/SPACECRAFT/ORBITER MATE AND CHECKOUT. The first-level Tug/spacecraft/Orbiter mate and checkout function flow diagram is shown in Figure 2-4. This flow corresponds to Exhibit 3-7 in Reference 1 modified to include a bypass flow line for payload installation at the launch pad. Related functional interface requirements data sheets follow the flow diagram.

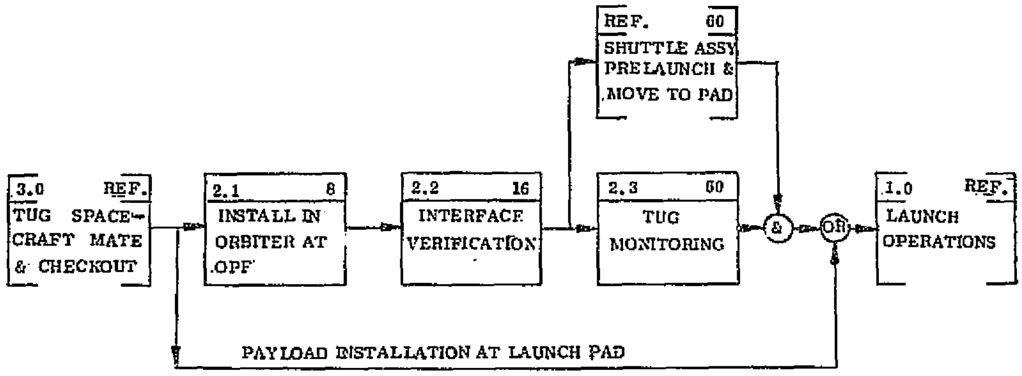

Figure 2-4. Space Tug Spacecraft Orbiter Mate and Checkout; Block 2.0, First-Level Functional Flow Diagram

FUNCTION FLOW BLOCK NO. 2.1	FUNCTION TITLE: Install in Orbiter at OPF	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

M Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.1.1 Verify Tug/Spacecraft mating and checkout		No Tug/Shuttle interface
2.1.2 Transport Tug/Spacecraft to OPF		No Tug/Shuttle interface
2.1.3 Remove covers & attach handling equipment		No Tug/Shuttle interface
2.1.4 Verify Orbiter payload bay door open & workstands in place; Orbiter support fitting beams, receptacles in proper position; Orbiter payload bay panels, MSS/PSS panels & all umbilicals in place.	Procedural	Provide instructions in Orbiter ground crew operations checklist to install necessary work platforms for Tug/Spacecraft loading.
2.1.5 Lift Tug/Spacecraft into Orbiter bay and secure mounting pads.	Structure	Provide attach fittings/mounting pads to fit lifting equipment and match Tug (payload) support provisions in Orbiter bay.
	Procedural	Provide instructions in Orbiter ground crew operations checklists to assist with this task.
2.1.6 Connect interface panels & verify	Avionics	Provide interface panel(s) receptacles for all Tug/Orbiter avionics interface connections.
	Fluid	Provide interface panels to accommodate all Tug/Orbiter fluid interface connections. NOTE: Implicit within these requirements is the requirement to provide avionics & fluid interface lines from interface panels on aft bulkhead of Orbiter bay to disconnect panels on the Orbiter mold line to connect with ground lines at launch pad.
	Procedural	Provide instructions in Orbiter ground crew operations checklist to provide access and support to accomplish this task.

Rev.

FUNCTION FLOW BLOCK NO. 2.1	FUNCTION TITLE: Install in Orbiter at OPS	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter　　___ Tug-Payload　　___ Tug-Payload-Orbiter

M Tug-GSE　　___ Tug-Facility

M = Mechanical Handling　　P = Propellant/Pressurant/Fluid　　A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.1.7 Remove handling equipment	Structure	Same as 2.1.5
	Procedural	Same as 2.1.5
		NOTE: Avionics/Fluid interfaces connected in 2.1.6 remain throughout subsequent prelaunch, launch, flight (thru deployment & subsequent to retrieval), landing and postlanding operations until Task 5.2.3.

Rev.

FUNCTION FLOW BLOCK NO. 2.2	FUNCTION TITLE: Interface Verification	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.2.1 Verify connection of fluid line interface panels	Fluid	Provide interface panels to accommodate all Tug-Shuttle fluid interfaces from Tug (or deployment adapter) to aft bulkhead and lines from aft bulkhead to Orbiter mold line disconnect panels.
	Structure	Provide hard point mounting locations for Orbiter bay work platforms to afford access to interface panels.
	Procedural	Provide instructions in Orbiter ground crew operations checklist to provide access and support for this task.
2.2.2 Connect leak test equipment, and	Fluid	Same as 2.2.1
2.2.3 Perform leak tests	Structure	Same as 2.2.1
	Procedural	Same as 2.2.1
		NOTE: Requirements to accomplish this task and determine availability of time in Orbiter Allocated Processing Plan. (Presently, there is not enough time for extensive leak tests.)
2.2.4 Verify connection of electrical (avionic) interface panels.	Avionics	Provide interface panels to accommodate all Tug-Shuttle avionics interfaces from Tug (or deployment adapter) to aft bulkhead and lines from there to Orbiter mold line disconnect panels and crew compartment umbilical lines and panels.
	Structure	Same as 2.2.1
	Procedural	Same as 2.2.1
2.2.5 Install electrical (avionics) check-out equipment & connect to LPS, and MSS/PSS.	Avionics	Same as 2.2.4
	Structure	Same as 2.2.1
	Procedural	Same as 2.2.1
2.2.6 Perform electrical tests.		NOTE: See note for Tasks 2.2.2 & 2.2.3
2.2.7 Remove GSE	Avionics	Same as 2.2.4
	Fluids	Same as 2.2.1
	Structure	Same as 2.2.1
	Procedural	Same as 2.2.1
2.2.8 Verify satisfactory completion of tests	Procedural	Provide instructions in Orbiter ground crew operations checklist to verify with Tug Test Conductor that tests are complete via completed test checklist QC signoff.

Rev.

FUNCTION FLOW BLOCK NO. 2.3	FUNCTION TITLE: Tug Monitoring	
	CONFIGURATION: All	Sheet 1 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

M Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.3.1 Install equipment to monitor critical Tug functions	Avionics	Provide instrumentation & data measurement capability to collect & display critical safety & warning parameters at a location external to the Orbiter payload bay. This location should be in one of the MLP rooms with available access during all Shuttle buildup & transport operations. This implies an interface path through the normal interface panels, out the bay aft bulkhead, to a disconnect panel on the Orbiter mold line. During Orbiter tow from OPF to VAB data could be displayed at payload/mission specialist station. Instrumentation for data gathering should be limited to normal flight instrumentation. All non-flight items must be located such that payload bay access is not required.
	Fluids	Provide all fluid interface lines required to maintain/replenish fluid system pressures such as MLI purge, retention of main thrust chamber in a stated null position or within specified limits of movement if required for clearance or load conditions. Fluid interface must also include provision for lines from payload bay aft bulkhead panels to disconnect panels on Orbiter mold line to mate with GSE rise-off disconnects.
	Structure	Provide hard points for positioning any required work or access platforms. NOTE: This requirement may be deleted if all connections and equipment are external to Orbiter and Orbiter payload bay.
	Procedural	Provide instructions in Orbiter ground crew operations checklist to provide access and/or assist with this task.

Rev.

FUNCTION FLOW BLOCK NO. 2.3	FUNCTION TITLE: Tug Monitoring	
	CONFIGURATION: All	Sheet 2 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

M Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.3.2 Activate monitor equipment recorders	Avionics	Same as 2.3.1, interface lines necessary to transmit data from Tug to recording/display location. Once activated, monitors & interface remain on until Task 1.1.
2.3.3 Remove payload bay workstands	Structure	Same as 2.3.1 NOTE: Utilization of Tug flight instrumentation should eliminate requirement to retain workstands until this task. Thus, they would probably be removed in Task 2.2.7 by - or under supervision of - Orbiter ground crew.
2.3.4 Close payload bay doors	--	No Tug-Shuttle interface (Orbiter task)
2.3.5 Prepare Orbiter for transport to VAB -	--	No Tug-Shuttle interface (Orbiter task)
2.3.6 Monitor Tug system status	Avionics	Use interface provided in Task 2.3.1 to monitor Tug status during Shuttle build-up, transport to launch pad and connect to GSE rise-off disconnect panels.
	Fluid	Use interface provided in Task 2.3.1 to replenish fluid supplies/pressure as required by Tug status & system requirements. Also connect to GSE rise-off disconnect panels during Orbiter pad hookup.
	Structure	Provide support points for Tug/Spacecraft & Tug deployment adapter capable of supporting them within payload bay with Orbiter in either horizontal or vertical (tail down) attitude. Further, support system must be capable of maintaining Tug/Spacecraft in proper position while Orbiter is towed from OPF to VAB, while Orbiter is being rotated from horizontal to vertical for Shuttle buildup, and during Orbiter transfer to the launch pad on the MLP.

Rev.

FUNCTION FLOW BLOCK NO. 2.3	FUNCTION TITLE: Tug Monitoring	
	CONFIGURATION: All	Sheet 3 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
2.3.6 (Continued)	Procedural	Provide instructions in Orbiter ground crew operations checklist to provide access and/or assist in connecting GSE rise-off disconnects to Orbiter mold line panels for all Tug system interfaces.

Rev.

2.1.3 LAUNCH OPERATIONS. The first-level launch operations function flow diagram is shown in Figure 2-5. This flow corresponds to Exhibit 3-8 in Reference 1 modified to resequence propellant loading (Block 1.2), add payload installation at the launch pad (Blocks 2.4 and 2.5), and add provisions for special functions associated with launch pad abort (Block 1.3A). Related functional interface requirements data sheets follow the flow diagram.

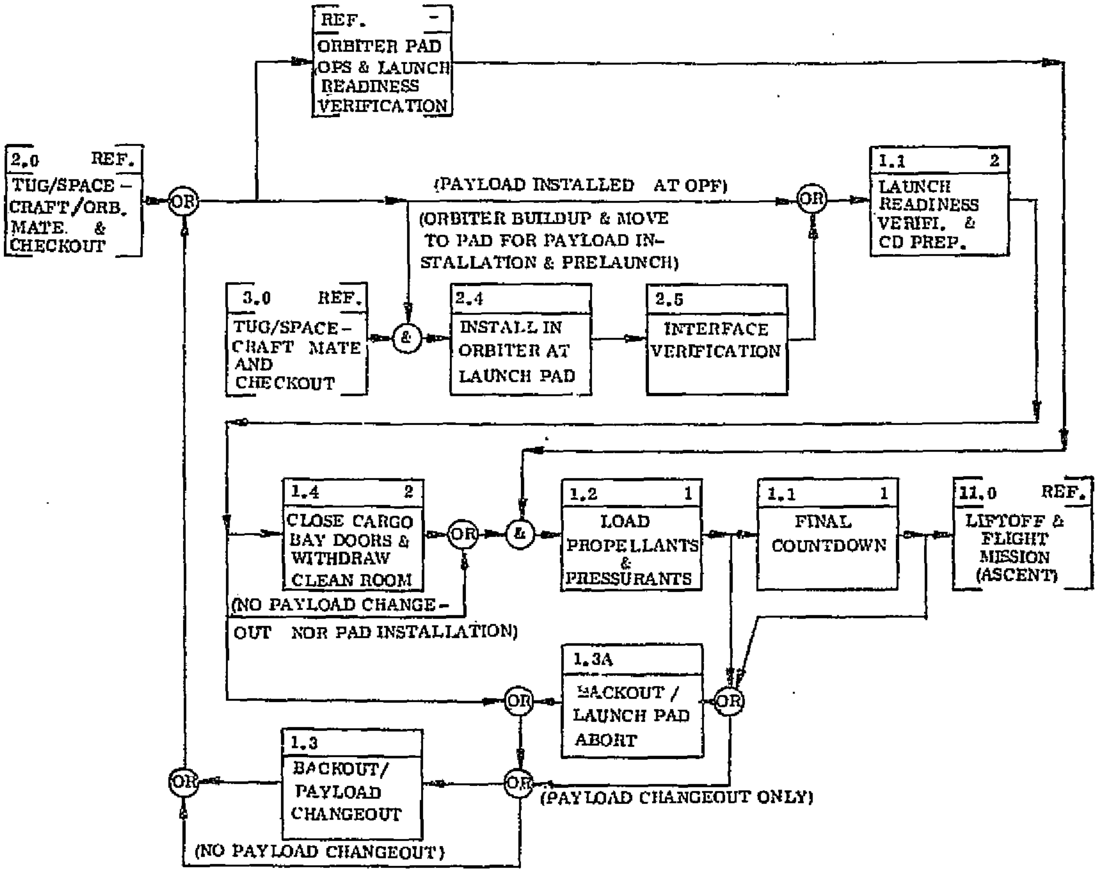

Figure 2-5. Space Tug Launch Operations

FUNCTION FLOW BLOCK NO. 1.1	FUNCTION TITLE: Launch Readiness Verif. & Countdown Prep.	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter   ___ Tug-Payload   ___ Tug-Payload-Orbiter

PA Tug-GSE   ___ Tug-Facility

M = Mechanical Handling   P = Propellant/Pressurant/Fluid   A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.1.1 Verify status of Tug propellant system	Structure	Provide support points for Tug & Tug deployment adapter capable of supporting Tug, spacecraft & adapter within payload bay with Orbiter in vertical attitude (tail down, Tug main engine down) in both empty and fully loaded condition (Task 1.2). In addition, this support system must accommodate both horizontal Tug/spacecraft installation (Task 2.1.5) & removal (Task 5.2.4) and vertical installation (Task 1.3.5) & removal (Task 1.3.3).
	Avionics	Provide instrumentation and data management capability to collect & display required propulsion system data at payload/mission specialist stations and to appropriate ground monitor & control stations. Interface lines required from Tug (Tug deployment adapter) through aft bulkhead interface panels to Orbiter stations and through rise-off disconnects to ground stations.
	Fluids	Provide instrumentation pickup/mounting to supply required propulsion system status to Data Mgmt subsystem for collection & display.
	Procedural	Include instructions in Shuttle prelaunch operations checklists to provide for accomplishment of this task. Provide required software to LPS if task or data display requires computer assist.

Rev.

FUNCTION FLOW BLOCK NO. 1.1	FUNCTION TITLE: Launch Readiness Verif. & Countdown Prep.	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.1.2 Activate each Tug system & verify status in conjunction with Shuttle pad preparation and Avionics Operations Test (AOT)	Structure	Same as 1.1.1
	Avionics	Same as 1.1.1, plus data management and capability to accept system activation commands, route to required Tug system and report response to ground control station and/or payload/mission specialist station in Orbiter. Provide required software to interface with LPS as required to accomplish task.
	Fluids	Same as 1.1.1, plus all other fluid systems provide instrumentation pickup/mounting to supply required data & response for verification tests. Data routed thru avionics data management system.
	Procedural	Same as 1.1.1
1.1.3 Verify Tug ready for terminal countdown	Structures	Same as 1.1.1
	Avionics	Same as 1.1.2
	Fluids	Same as 1.1.2
	Procedural	Same as 1.1.2
1.1.4 Monitor Tug status during final Shuttle prelaunch and countdown preparation operations.	Structure	Same as 1.1.1
	Avionics	Same as 1.1.2
	Fluids	Same as 1.1.2
	Procedural	Same as 1.1.2

Rev.

FUNCTION FLOW BLOCK NO. 1.2	FUNCTION TITLE: Load Propellants & Pressurants	
	CONFIGURATION: All	Sheet 1 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.2.1 Purge propellant system	Structure	Continue to provide support points for Tug and Tug adapter
	Fluids	Provide interface panels (aft bulkhead & Orbiter mold line) and lines to accomplish propellant tank purge. Requires lines for ground pressurization/purge and LH_2/LO_2 tank vent.
	Avionics	Provide instrumentation, data management, interface panels (aft bulkhead & Orbiter mold line) and lines to monitor and control tank purge operations. Provide interface with LPS for pre-launch & countdown data display at appropriate ground control stations. Provide LPS interface software as required.
	Procedural	Provide instructions for Shuttle & LPS pre-launch & countdown operations checklists.
1.2.2 Verify systems ready for loading.	Structure	Same as 1.2.1
	Avionics	Essentially same as 1.2.1, and that required for 1.1.1 (verify propellant system status). Within interface panels and lines, provide for total propulsion system status monitor & display.
	Fluids	Provide instrumentation pickup/mounting to supply required propulsion system status data to Data Management subsystem for collection and display.
	Procedural	Same as 1.2.1
		Rev.

FUNCTION FLOW BLOCK NO. 1.2	FUNCTION TITLE: Load Propellants & Pressurants	
	CONFIGURATION: All	Sheet 2 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.2.3 Load helium system	Structure	Same as 1.2.1
	Fluids	Provide necessary interface panels (Orbiter aft bulkhead & mold line) and lines to accomplish helium system fill, vent and status monitor during system load and subsequent final count-down. Provide instrumentation pickup/ mounting to supply required status data to Data Management subsystem for collection and display.
	Avionics	Provide instrumentation, data management, interface panels (Orbiter aft bulkhead and mold line) and lines to monitor & control helium loading. Provide interface with LPS for loading & countdown data display at appropriate ground control stations. Provide LPS interface software as required.
	Procedural	Same as 1.2.1
1.2.4 Load hydrogen system	Fluids	Same as 1.2.3, except for hydrogen fill, drain, vent and status monitoring.
	Avionics	Same as 1.2.3, except to monitor & control hydrogen system fill, vent and drain.
	Structure	Same as 1.2.1
	Procedural	Same as 1.2.1
1.2.5 Load oxygen system	Fluids	Same as 1.2.3, except for oxygen fill, drain, vent & status monitoring.
	Avionics	Same as 1.2.3, except to monitor & control oxygen system fill, vent & drain.
	Structure	Same as 1.2.1
	Procedural	Same as 1.2.1

Rev.

FUNCTION FLOW BLOCK NO. 1.2	FUNCTION TITLE: Load Propellants & Pressurants	
	CONFIGURATION: All	Sheet 3 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.2.6 Load ACPS system Note: Will probably be accomplished in Payload Changeout Room (PCR)	Fluids	Same as 1.2.3, except for ACPS N_2H_4 fill, vent, drain and status monitor.
	Avionics	Same as 1.2.3, except to monitor & control ACPS fill, vent & drain.
	Structure	Same as 1.2.1
	Procedural	Same as 1.2.1
1.2.7 Load fuel cell reactants	Fluids	Same as 1.2.4 & 1.2.5 since fuel cells probably use reactants from Tug main LH_2 & LO_2 propellant tanks.
	Avionics	Same as 1.2.4 & 1.2.5 since fuel cells probably use reactants from Tug main LH_2 & LO_2 propellant tanks.
	Structure	Same as 1.2.1
	Procedrual	Same as 1.2.1
1.2.8 Place Tug & GSE in standby condition	Fluids Avionics Structure Procedural	Same as 1.2.1 thru 1.2.7 for all systems
1.2.9 Replenish cryogenic tanks	Structure	Same as 1.2.1
	Fluids	Provide interface panels in Orbiter payload bay aft bulkhead and on Orbiter mold line and lines between those panels to accomplish liquid oxygen and liquid hydrogen topping/replenish operations. Provide lines for replensih fill, vent and tank pressurization as required.
	Avionics	Provide instrumentation and data management capability for monitor & control of replenish operations. Provide interface panels (aft bulkhead & mold line) and lines to transmit replenish status.

Rev. A

FUNCTION FLOW BLOCK NO. 1.2	FUNCTION TITLE: Load Propellants & Pressurants	
	CONFIGURATION: All	Sheet 4 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.2.9 (Continued)	Avionics (Cont'd.)	data to payload/mission specialist panel and appropriate ground control stations. Provide required interface software for LPS and Shuttle pre-launch operations.
	Procedural	Provide instruction input to Shuttle pre-launch operations checklist to accomplish & monitor this task.

Rev.

FUNCTION FLOW BLOCK NO. 1.3	FUNCTION TITLE: Backout/Payload Changeout	
	CONFIGURATION: All	Sheet 1 of 4

INTERFACE:

MPA Tug-Orbiter ____ Tug-Payload ____ Tug-Payload-Orbiter

PA Tug-GSE ____ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
NOTE: Payload changeout tasks & functional interface requirements are based on payload changeout occurring prior to attaining final two hour standby status and; therefore, prior to propellant loading. The changeout room is in place with an environmental seal established between the room & Orbiter skin, and the payload bay doors are closed.		
1.3.1 Attach GSE & open payload bay doors		Orbiter task - no Tug Orbiter interface.
1.3.2.1 Install workstands	Structural	Provide structural support points for workstands. (May be provided by Orbiter.) Provide structural support for Tug and adapter within Orbiter payload bay.
1.3.2.2 Safe Tug	Structural	Same as 1.3.2.1
	Avionics	Provide instrumentation & data management capability to place Tug systems in safe condition, verify accomplishment and display data on Orbiter mission/payload specialist panel and appropriate ground control panels. Includes providing all interface lines and panels to transmit data from Tug to Orbiter and ground locations.
	Fluids	Provide means to secure insulation purge system in safe condition, verify accomplishment, and display results at appropriate Orbiter and ground control stations.
	Procedural	Provide input to Orbiter ground operations checklist to accomplish this task. Provide required software input to LPS to accomplish this task if computer assist is required.

Rev.

FUNCTION FLOW BLOCK NO. 1.3	FUNCTION TITLE: Backout/Payload Changeout	
	CONFIGURATION: All	Sheet 2 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.3.2.3 Disconnect interface connectors	Avionics	Provide interface panel(s)/receptacles for all Tug-Shuttle avionics interface connections and for all Tug to ground interfaces routed through Orbiter to ground. (Ref. Task 2.1.6 for interface connection.)
	Fluid	Provide interface panels to accommodate all Tug/Orbiter fluid interface connections and for all Tug to ground interfaces routed through Orbiter to ground. (Ref. Task 2.1.6 for interface connection. Ref. Task 1.2 for identification of fluid subsystems involved.)
	Structural	Same as 1.3.2.1
	Procedural	Same as 1.3.2.2
1.3.2.4 Attach payload changeout unit	Structural	Same as 1.3.2.1. Support points for payload changeout unit & handling equipment must not interfere with normal Orbiter-Tug support points or payload bay clearance requirements.
	Procedural	Same as 1.3.2.2
1.3.2.5 Remove workstands	Structural	Same as 1.3.2.1
	Procedural	Same as 1.3.2.2
1.3.3 Remove Tug/spacecraft & deployment adapter to clean room	Structural	Same as 1.3.2.4
	Procedural	Same as 1.3.2.2
1.3.4 Replace Tug and/or spacecraft and verify interface.	—	No Tug-Orbiter interfaces involved in this task.
1.3.5 Install Tug and/or spacecraft in Orbiter bay & verify interfaces	—	See sub-task steps

Rev.

FUNCTION FLOW BLOCK NO. 1.3	FUNCTION TITLE: Backout/Payload Changeout	
	CONFIGURATION: All	Sheet 3 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.3.5.1 Install Tug and/or spacecraft	Structural	Provide Tug & Tug adapter support points & latches to fix their position in the payload bay for subsequent propellant loading & flight loads. Support points must not interfere with payload changeout unit & other handling GSE. NOTE: Task 1.3.5 is essentially same with respect to determining functional interface requirements, as the optional launch pad installation concept.
	Procedural	Provide input to Orbiter ground operations checklists to accomplish or assist with this task.
1.3.5.2 Reinstall work platforms as necessary to provide access to interface panel locations.	Structural	Provide structural hard points for access work platforms. (May be provided by Orbiter) Continue to provide Tug & deployment adapter support hard points as in 1.3.5.1.
	Procedural	Same as 1.3.5.1
1.3.5.3 Connect interface panels.	Structural	Same as 1.3.5.2
	Avionics	Provide interface panel(s) or receptacles for all Tug-Orbiter avionics interface connections. (Ref. Task 2.1.6 for horizontal connection task.) Panels must be located to facilitate access for connection with Tug & Orbiter in either horizontal or vertical attitude.
	Fluids	Provide interface panels to accommodate all Tug/Orbiter fluid interface connections and for all Tug-ground interfaces routed thru the Orbiter. (Ref. Task 2.1.6 for horizontal connection & Task 1.2 for fluid subsystem identification.)

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FUNCTION FLOW BLOCK NO. 1.3	FUNCTION TITLE: Backout/Payload Changeout	
	CONFIGURATION: All	Sheet 4 of 4

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.3.5.3 (Cont'd.)	Fluids (Cont'd.	Panels must be located to facilitate access with Tug & Orbiter in either horizontal or vertical attitude.
	Procedural	Same as 1.3.5.1
1.3.5.4 Verify interface connections	Structural	Same as 1.3.5.2
	Avionics	Same as 1.3.5.3 plus interface to ground control stations.
	Fluids	Same as 1.3.5.3 plus interface to ground fluid systems and ground control stations.
	Procedural	Same as 1.3.5.1, plus required software input to LPS to accomplish all ground-controlled verification and status checks.
1.3.6 Remove workstands & detach payload changeout unit.	Structural	Provide Tug & Tug deployment adapter support points & latches to fix their position in the payload bay. Provide support for workstands.
	Procedural	Provide input to Orbiter operations checklists to accomplish or support this task.
1.3.7 Initiate purges & return to standby status.	Structural	Continue to provide support for Tug & Tug adapter.
	Avionics	Provide avionics interface panel(s)/ receptacles to control & monitor main propellant tank insulation purges. Provide required software input to LPS.
	Fluids	Provide fluid system interface panels for main propellant tank insulation purge and vent.
	Procedural	Same as 1.3.5 to initiate & monitor purge operations.

Rev.

FUNCTION FLOW BLOCK NO. 1.3A	FUNCTION TITLE: Backout	
	CONFIGURATION: Pad Abort	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.3.1A Terminate propellant loading if still in progress. (Or, terminate topping if in progress.)	Structural	Provide support and latch or restraint devices to maintain Tug & deployment adapter in vertical position during launch pad backout activities.
	Avionics	Provide instrumentation & data management capability to monitor and control Tug propellant loading /termination operations and display required data at payload/mission specialist station and ground control stations. Includes interface panels at Orbiter mold line & aft bulkhead and all interconnecting lines
	Fluids	Provide all fluid system interface panels (Orbiter mold line & payload bay aft bulkhead) and interconnecting lines to accomplish main propellant load, terminate, drain; ACPS propellant load terminate & drain; and helium relief.
	Procedural	Provide input to launch operations checklist to accomplish this task. Provide required LPS software input to support task.
	Environment	Provide payload bay GN_2 purge while cryo-propellants are in Tug main tanks.
1.3.2A Return Tug systems to safe hold status	Structures, Avionics, Fluids, Procedures & Environment	Same as 1.3.1A for all systems
1.3.3A Flight crew egress (if on board)	Structures	Same as 1.3.1A
	Procedural	Orbiter crew task, no Tug-Orbiter interface.

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FUNCTION FLOW BLOCK NO. 1.3A	FUNCTION TITLE: Backout	
	CONFIGURATION: Pad Abort	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.3.4A Accomplish propellant drain: a. LH_2 b. LO_2 c. ACPS	Structural, Avionics, Fluids, Procedural & Environment	Same as 1.3.1A for all systems
1.3.5A Purge propellant systems	Structures & Avionics	Same as 1.3.1A
	Fluids	Provide ground pressure source via fluid system interface panels & lines for propellant tank purge.
	Procedural	Same as 1.3.1A
1.3.6A Vent & safe pressurization systems	Structures	Same as 1.3.1A
	Avionics	Provide control & monitor capability for vent & safing thru existing avionics interface panels & lines.
	Fluids	Provide LO_2&LH_2 vent system interface panels & lines to vent tanks thru Orbiter to ground locations (vent stack or burn pond). Venting can not be permitted into the Orbiter payload bay.
	Procedural	Same as 1.3.1A
1.3.7A Secure all systems in safe condition	Structural, Avionics, & Procedural	Same as 1.3.1A
	Fluids	Same as 1.3.1A plus 1.3.6A

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FUNCTION FLOW BLOCK NO. 1.4	FUNCTION TITLE: Close Cargo Bay Doors, etc.	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.4.1 thru 1.4.5 NOTE: These are basically Orbiter tasks to secure from payload changeout or pad installation. During these tasks the functional interfaces identified must be maintained, but are not associated with a discrete Orbiter sub-task.	Structure	Continue to provide hard point support & latches to maintain Tug & deployment adapter position within payload bay.
	Avionics	Provide instrumentation, data management, interface panels (Orbiter aft bulkhead & mold line) and lines to monitor Tug status during this & other Orbiter pre-launch and standby activity. Provide interface with LPS for data display at appropriate ground control stations as well as caution & warning display at payload/mission specialist panel. Provide required interface software.
	Fluids	Provide interface panels (Orbiter aft bulkhead & mold line), lines, instrumentation mounting/pickup to supply required fluid-system status data to Data Management for collection & display. Also, provide fluid (helium, LH_2, LO_2 and N_2H_4) interface panels & lines for required system fill, drain, vent, purge or topping operations.
	Procedural	Provide input to Orbiter ground operations checklist to accomplish or support Tug monitoring during Orbiter final pre-launch operations.

Rev.

FUNCTION FLOW BLOCK NO. 1.5	FUNCTION TITLE: Final Countdown	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

PA Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
1.5.1 Verify Tug system status	Structure	Continue to provide support points for Tug, deployment adapter & spacecraft.
	Fluids	Provide interface panels (Orbiter aft bulkhead & mold line), lines, instrumentation mounting/pickup to supply required fluid systems status data to Data Management system for collection and display. Also, all helium, hydrogen, oxygen & N_2H_4 interface panels and lines which may be required for respective system fill, drain, vent or purge.
	Avionics	Provide instrumentation, data management, interface panels (Orbiter aft bulkhead & mold lines), and lines to monitor Tug status. Provide interface with LPS for pre-launch & countdown data display at the appropriate ground control station as well as caution & warning display at payload/mission specialist station. Provide required interface software.
	Procedural	Provide instructions for Shuttle & LPS pre-launch countdown operations check-lists.
1.5.2 Control & monitor Tug during terminal countdown	Structural, Fluids, Avionics & Procedural	Same requirements as 1.5.1, all systems.

Rev.

2.1.4 FLIGHT OPERATIONS-ASCENT PHASE. The first level flight operations-ascent phase function flow diagram is shown in Figure 2-6. This flow was derived by Convair based on data in the Baseline Tug Flight Operations (Reference 2) document and the Tug Operations and Payload Support Study (Reference 3) final report. It covers all activities from Tug/Shuttle launch through Tug/Spacecraft separation from the Orbiter and transfer of control to mission ground control. The related function interface requirements data sheets follow the flow diagram.

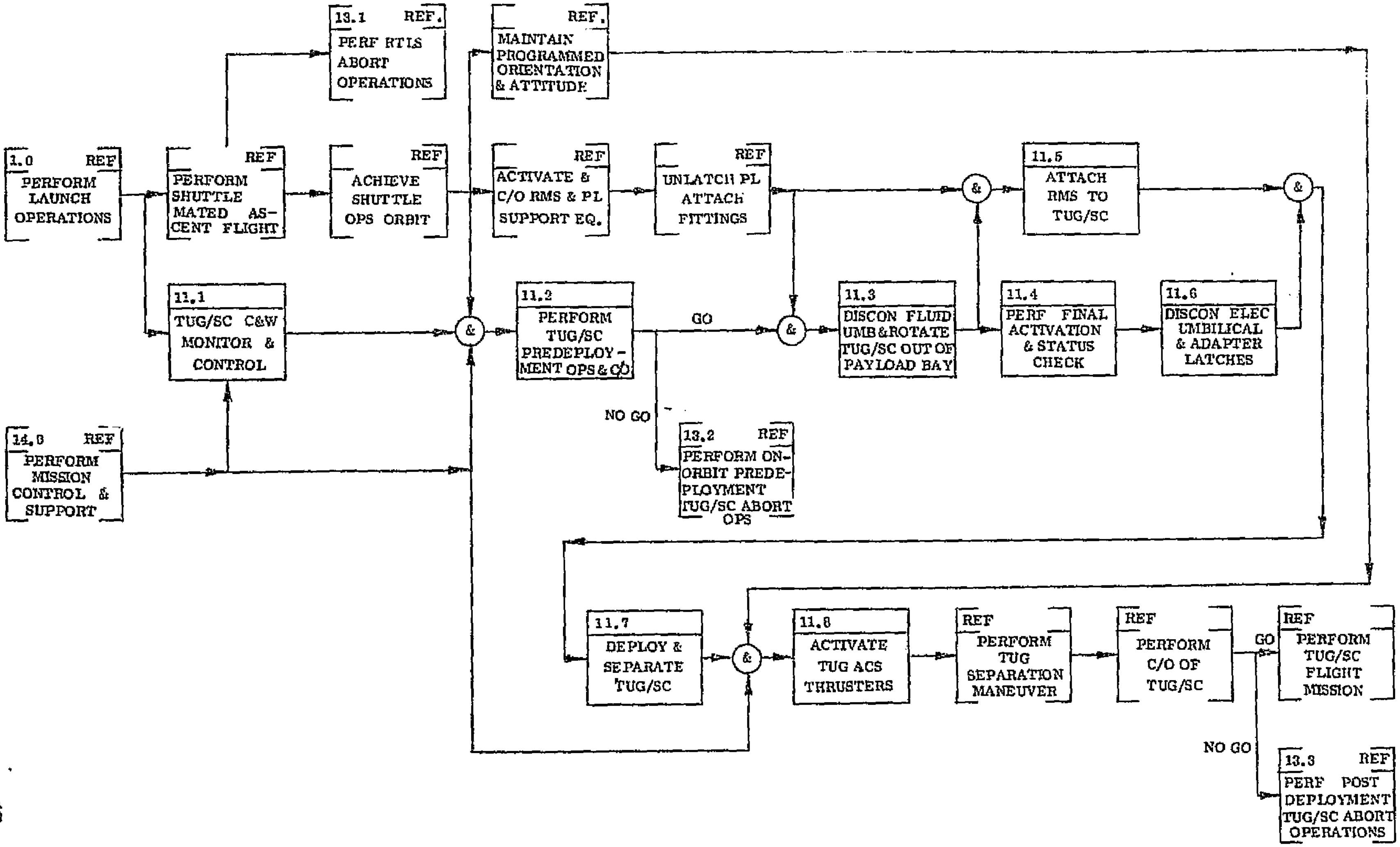

Figure 2-6. Space Tug, Perform Flight Mission, Ascent Phase; Block 11.0, First-Level Functional Flow Diagram

FUNCTION FLOW BLOCK NO. 11.1	FUNCTION TITLE: Tug/SC Caution & Warning Monitor & Control	
	CONFIGURATION: All	Sheet 1 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.1.1 Lift-off of mated Shuttle & Tug/SC	Avionics	• Provide control and monitoring capability to automatically perform following functions at Orbiter ignition or first movement of Shuttle to: . Close LH_2 and LO_2 tank vent valves. . Terminate helium purge. . Purge bag vent valves are open • Manual override capability is to be provided from Orbiter crew compartment control panel.
Note: All warning monitor and control circuits must be hardwired from C&W panel to appropriate function. Number of functions to be monitored and controlled should be reduced to those functions necessary to ensure Orbiter and crew safety. It must be realized that Shuttle flight involves risk and the only requirement for Tug and SC C&W is not to unduly increase this risk. Requirements for C&W will be issued by safety personnel.		• Provide C&W monitor and control panel in crew compartment. This panel will be interconnected with Orbiter flight crew displays and controls, aural alarm and illuminated talkback. In addition, provide C&W data to be transmitted through Orbiter communication system to ground stations and ground controllers. • Provide electrical power. (Note: Subject to trade study to determine whether power is provided by Orbiter or Tug fuel cells are activated for ascent power. • Provide capability to record C&W data and Tug flight performance data. • Relay C&W data to ground station.
	Procedure	• Provide instructions for appropriate control functions to be executed by Orbiter crew based on C&W signals. • Monitor and control C&W display/panel.

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FUNCTION FLOW BLOCK NO. 11.1	FUNCTION TITLE: Tug/SC Caution & Warning Monitor & Control	
	CONFIGURATION: All	Sheet 2 of 3

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.1.1 Cont'd.	Fluids	• Provide fluid interface lines and panels for LO_2 and LH_2 tank vent and pressurization. Provide pressurization gas supply. • Provide purge bag vent line.
11.1.2 Shuttle powered flight	Avionics	• Provide control and monitoring capability to automatically perform following function during powered flight of Shuttle. . Open LH_2 and LO_2 tank vent valves at ~200 secs. or ≥ 300,000 ft altitude. • Provide manual override capability from Orbiter crew compartment C&W panel. • C&W monitor and control panel, same as 11.1.1.
	Procedural	Same as 11.1.1
	Fluid	Same as 11.1.1
11.1.3 Shuttle operational orbit monitor and control	Avionics	• C&W monitor and control primary responsibility to be switched to mission specialist station (MSS). Panel planned for that location. Status data for Tug/SC to be transmitted to ground station through Orbiter communication link either STDN for NASA missions or SGLS for DoD missions. (Baseline RF Orbiter to ground station is assumed to be TDRS subnet for NASA missions, providing 90% orbital coverage at 160 n.mi. orbit. DoD AFSCF/SGLS

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FUNCTION FLOW BLOCK NO. 11.1	FUNCTION TITLE: Tug/SC Caution & Warning Monitor & Control	
	CONFIGURATION:	Sheet 3 of 3

INTERFACE:

MPA Tug-Orbiter   ___ Tug-Payload   ___ Tug-Payload-Orbiter

___ Tug-GSE   ___ Tug-Facility

M = Mechanical Handling   P = Propellant/Pressurant/Fluid   A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.1.3 Cont'd.	Avionics	is assumed to be via 11 remote tracking stations located at eight geographical stations providing approximately 15% communication coverage per orbit.) • Provide controls to activate zero g vent systems and close positive g vent valves.
	Fluids	• Provide zero g vent system and mixer.
	Procedure	• Perform C&W monitor and control from MSS. • Record C&W data. • Transmit status data to ground station.

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FUNCTION FLOW BLOCK NO. 11.2	FUNCTION TITLE: Perform Tug/SC Predeployment Operations & Checkout	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.2.1 Transfer control of Tug/SC to ground controller (missions using synchronous communication satellite — TDRS) Note: Alternative Tug checkout methodology is to perform function from Orbiter with ground monitoring c/o activity. This method is probably more compatible with STDN/ground subnet and AFSCF/RTS. In addition, rather than storing activation and checkout program in Tug DMS, this function can be stored in Shuttle computer or in Tug SSE.	Avionics	• Provide through Orbiter communication system authority to receive command data and transmit status data from/to ground stations. • In Tug DMS provide program to perform predeployment activation and checkout. (It is assumed SC DMS would have similar activation and checkout program if SC predeployment checkout is prescribed.) • Provide backup program capability in Orbiter.
	Procedure	• Provide instructions for orbiter mission specialist to monitor activation and checkout procedure and provide assistance as requested by ground controller.
	Structure	• Provide primary structural support of Tug and deployment adapter in Orbiter during Shuttle liftoff and powered flight. Support must be compatible with Orbiter support locations, interface surface details, and loads/strength.
	Fluid	• Provide fluid interface lines and panels for LO_2 and LH_2 vent and pressurization. • Provide pressurization gas supply. • Provide purge bag vent lines.
11.2.2 Perform Tug predeployment activation and checkout	Avionics	• Provide communication link to Orbiter to receive ground command to initiate programmed Tug predeployment activation and checkout. • Relay ground commands to Tug to initiate activation and checkout. • Relay Tug status to ground station. • Provide capability to store Tug data in Orbiter.

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·UNCTION FLOW BLOCK NO. 11.2	FUNCTION TITLE: Perform Tug/SC Predeployment Operations & Checkout	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.2.2 Cont'd.	Procedure	• Monitor Tug checkout operation. • Provide backup assistance to ground control as requested.
	Structure	Same as 11.2.1
	Fluid	Same as 11.2.1
11.2.3 Perform SC predeployment activation and checkout (optional function depending on SC program)	Avionics	• Provide hardwire link from Orbiter through Tug to SC to initiate activation and checkout of SC subsystems. • Provide hardwire link to transmit status data from SC through Tug to Orbiter. • Provide capability to receive commands and relay to SC through Tug and to transmit SC status data to ground station. • Provide capability to store status data.
	Procedure	Same as 11.2.2, except for SC
	Structure	Same as 11.2.1
	Fluid	Same as 11.2.1
11.2.4 Commit to deploy (including disconnect of Tug-Orbiter fluid interface panels	Avionics	• Provide indication for Tug/SC systems in go status for deployment. (No-go status results in abort condition, see Block 12.2.) • Provide capability for visual monitoring of Tug/SC through CCTV to verify go status. • Receive verification of go status from ground controller.
	Procedure	Same as 11.2.2
	Structure	Same as 11.2.1, plus release Orbiter/Tug support fitting latches.
	Fluid	• Provide disconnect panels in interface lines to enable disconnecting fluid lines prior to or concurrent with Tug rotation.

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FUNCTION FLOW BLOCK NO. 11.3	FUNCTION TITLE: Rotate Tug/SC Out of Payload Bay	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.3.1 Activate deployment adapter drive mechanism	Mechanical/ Structure	Same as 11.1 plus: • Provide drive mechanism to rotate Tug/SC deployment adapter out of Orbiter payload bay/disconnect fluid umbilicals.
Note: Alternative means of rotating Tug/SC out of payload bay is through use of RMS to provide force.	Avionics	• Provide controls to initiate and operate drive mechanism. • Provide instrumentation and DMS display capability to verify status of drive mechanism. • Provide communication link to transmit status information to Orbiter communication for relay of data to ground controllers. • Provide electrical power. • Provide lights and CCTV to visually inspect Tug/SC readiness for deployment. • Provide controls to release Tug forward attachment latches.
	Procedure	• Provide instructions to Orbiter crew to orient Orbiter and maintain attitude for Tug deployment (desired orientation is to align Orbiter X-axis along the radial vector from center of earth. Nose of Orbiter is pointed away from earth.
11.3.2 Deploy Tug/SC	Mechanical/ Structure	• Provide locking mechanism to position Tug/SC at preprogrammed rotation angle.
	Avionics	• Provide controls to perform rotation Tug/SC. • Provide instrumentation DMS and data link to monitor operation and Tug/SC status. • Provide electrical power.

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FUNCTION FLOW BLOCK NO. 11.3	FUNCTION TITLE: Rotate Tug/SC Out of Payload Bay	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MA Tug-Orbiter   ___ Tug-Payload   ___ Tug-Payload-Orbiter

___ Tug-GSE   ___ Tug-Facility

M = Mechanical Handling   P = Propellant/Pressurant/Fluid   A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.3.2 Cont'd.	Avionics (Cont'd.)	• Relay Tug/SC operation and status to ground controller.
	Procedure	• Maintain programmed orientation and attitude during deployment operation. • Provide lights and CCTV to visually monitor operation.

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FUNCTION FLOW BLOCK NO. 11.4	FUNCTION TITLE: Perform Tug Final Activation and Status Check	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter | ___ Tug-Payload | ___ Tug-Payload-Orbiter

___ Tug-GSE | ___ Tug-Facility

M = Mechanical Handling | P = Propellant/Pressurant/Fluid | A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.4.1 Tug activation complete	Structure	• Provide Tug/SC support through the deployment adapter and adapter fittings.
	Avionics	• Provide controls and DMS to open non-thrust vents for H_2 and O_2. • Provide controls to disable zero g vent devices. • Provide controls to activate fuel cell and changeover power from Orbiter to internal. • Provide data link to update G&N state vector. • Provide RF link for Tug to communicate with Orbiter and ground after umbilical panel disconnect.
	Procedure	• Maintain orientation and attitude during operation.
11.4.2 Tug status verification and commit to deploy	Avionics	• Provide instrumentation DMS, data link to verify Tug readiness and commit to deploy. Tug computer program to perform verification on command from ground controller or Orbiter crew. • Provide status data to Orbiter and to relay to ground controllers. • Provide voice and data uplink for ground controller to verify Tug/SC commit to deploy.
	Procedural	Same as 11.4.1
	Structure	Same as 11.4.1

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FUNCTION FLOW BLOCK NO. 11.5	FUNCTION TITLE: Attach RMS to Tug/SC	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.5 Attach RMS to Tug/SC	Mechanical/ Structure	• Provide RMS mating mechanical fitting on Tug to mate with RMS end effector. • Continue to provide Tug support through deployment adapter.
	Avionics	• Provide capability to visually monitor attachment of RMS and subsequent deployment operations using CCTV and necessary lighting system.
	Procedure	• Provide instructions to MSS operator to accomplish these tasks.

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FUNCTION FLOW BLOCK NO. 11.6	FUNCTION TITLE: Disconnect Umbilical and Adapter Latches
	CONFIGURATION: Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.6.1 Disconnect Tug electrical umbilicals Note electrical umbilicals may be disconnected concurrently with Tug/deployment adapter separation in 11.6.2	Avionics	• Provide controls to initiate retracting Tug deployment adapter to vehicle umbilical panels. • Provide instrumentation and DMS link to monitor demating operation from MSS display and also at ground controller station.
	Mechanical/ Structure	• Provide drive mechanism to respond to command performing demating of electrical umbilical panels from Tug vehicle. • Continue to provide Tug support through deployment adapter.
	Procedural	• Provide instructions to Orbiter crew to accomplish this task.
11.6.2 Release deployment adapter latches	Avionic	• Provide controls to initiate demating of Tug vehicle from deployment adapter. • Provide instrumentation and DMS link to monitor release operation from MSS display console and also at ground controller station.
	Mechanical/ Structure	Same as 11.6.1, plus: • Provide mechanism to release deployment adapter latches from vehicle.
	Procedural	Same as 11.6.1, and • Maintain orientation and attitude during operation.

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FUNCTION FLOW BLOCK NO. 11.7	FUNCTION TITLE: Deploy and Separate Tug/SC	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.7.1 Position Tug/SC by withdrawing from deployment adapter and positioning in release position.	Structure/ Mechanical	• Provide attach socket for RMS end effectors located to permit withdrawal from deployment adapter.
	Avionics	• Provide capability to visually monitor this operation from MSS panel as in 11.5. • Provide instrumentation, DMS and communication to transmit Tug status data to Orbiter for monitor and control.
	Procedure	• Provide instructions to MSS operator to accomplish this task.
11.7.2 Separate Tug/SC	Avionics	• Provide control, data link to enable ACS. • Provide instrumentation, DMS and data link to monitor and control Tug operation and performance at ground station through Orbiter.
	Structure/ Mechanical	• Release RMS from Tug socket.
	Procedure	Provide instructions for Orbiter crew to: • Perform separation maneuver. • Relay telemetry and command data from/to Tug to/from ground station. Provide instructions for ground crew to: • Establish direct RF link to Tug and assume flight control responsibility after attaining proper separation distance.

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FUNCTION FLOW BLOCK NO. 11.8	FUNCTION TITLE: Activate Tug ACS Thrusters	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

A Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
11.8 Activate Tug ACS Thrusters	Avionics	• Provide controls, communication subsystem, and data links to receive command and send signal to ACS subsystem to energize ACS thruster propellant control valves.
	Procedure	• Transmit command to activate Tug ACS. • Continue relaying status data to ground station. • Perform separation maneuver. • Transfer control of Tug to ground controller.

Rev.

2.1.5 FLIGHT OPERATIONS-TUG RETRIEVAL AND LANDING. The first level flight operations-Tug retrieval and landing function flow diagram is shown in Figure 2-7. This flow was derived by Convair based on data in the Baseline Tug Flight Operations (Reference 2) document and the Tug Operations and Payload Support Study (Reference 3) final report. It covers all activities from re-establishing the Tug/Orbiter RF link interface for retrieval through stowage in the payload bay, entry, and landing. The related functional interface requirements data sheets follow the flow diagram.

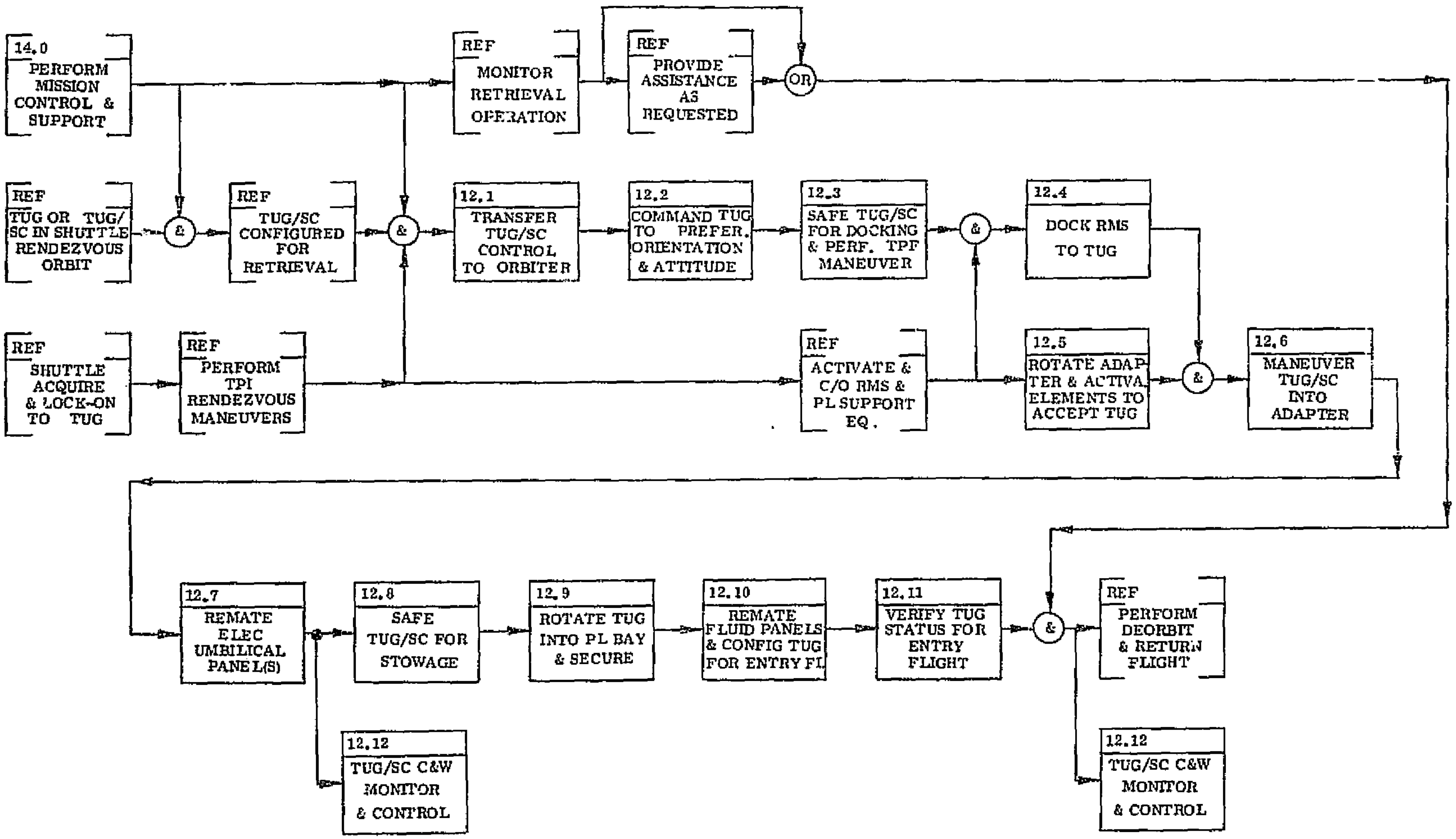

Figure 2-7. Space Tug, Perform Flight Mission, Tug/SC Retrieval; Block 12.0, First-Level Functional Flow

FUNCTION FLOW BLOCK NO. 12.1	FUNCTION TITLE: Transfer Tug/SC Control to Orbiter	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

A Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.1 Transfer Tug/SC control from ground controller to Orbiter crew	Avionics	• Provide communication system compatible with AFSCF & STDN (TDRS) networks. • Provide RF compatibility with Orbiter as well as ground stations. • Provide capability for Tug/SC to receive 24 Kbps information rate & total of 8 Kbps encoded cmd data with BER of 10^{-5}. • Provide capability to transmit 16 Kbps TM data Tug and S/C to Orbiter.
NOTE: Tug/SC retrieval by Orbiter is based on following guidelines: • SC is inert & safed with all appendages retracted into stowed position. • Only service provided SC is thermal control thru electrical power supplied by Tug (CMD & TLM) • Tug MPS has been safed. All propellants, other than FPR, have been expended prior to rendezvous maneuvers by Orbiter. • Tug active subsystems are communication, DMS, G&N and ACS.	Procedure	• Transfer prime operational responsibility of Tug/SC from mission control to Orbiter for rendezvous and docking operations. Mission control will monitor Tug activity as relayed thru Orbiter RF comm link with ground stations.

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FUNCTION FLOW BLOCK NO. 12.2	FUNCTION TITLE: Command Tug to Preferred Orientation & Attitude	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

A Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.2.1 Orient Tug/SC	Avionics	• Provide transponder compatible with Orbiter radar for rendezvous. • Provide communication, DMS & flight control to receive commands and compute signals for ACS. • Provide instrumentation, DMS & Data link to transmit status data to Orbiter.
	Procedure	• Provide instructions for Orbiter crew to: • Issue commands to orient & position Tug/SC for rendezvous & docking. • Receive status data & monitor Tug operations & performance. • Relay TM data to ground station.
12.2.2 Stabilize Tug/SC	Avionics & Procedure	Same as 12.2.1

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FUNCTION FLOW BLOCK NO. 12.3	FUNCTION TITLE: Safe Tug for Docking & Perform TPF Maneuver	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

A Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.3.1 Perform safing operations	Avionics	• Provide instrumentation, DMS and communication subsystems to verify status & safety of Tug/SC. Transmit measurements, excitation & commands to other subsystems. Transmit status & safety data to Orbiter. • Provide G&N, DMS & flight control to to maintain commanded orientation and attitude. • Provide controls to deactivate transponder at direction of Orbiter.
	Procedure	Provide instructions for Orbiter crew to • Perform TPI and TPF rendezvous maneuvers. • Verify all Tug/SC subsystems safed for docking except ACS and communication cmd link.
12.3.2 Perform TPF maneuvers	Avionics	• Provide ACS, communication link to receive Orbiter commands and execute. Transmit status to Orbiter and to position Tug to preferred docking attitude.
	Procedure	Provide instructions for Orbiter crew to • Visually inspect Tug/SC for docking readiness. • Maneuver to docking attitude & location. • Translate to final docking station.

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FUNCTION FLOW BLOCK NO. 12.4	FUNCTION TITLE: Dock RMS to Tug	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.4.1 Attach RMS to Tug	Structure/ Mechanical	Provide fitting/receptacle compatible with RMS end effector (Ref. Task 11.5).
	Avionics	• Provide controls to transmit commands to ACS to stabilize Tug/SC for mating with RMS. • Shutdown ACPS. • Provide CCTV & lights to visually monitor RMS-Tug mating.
	Procedure	Provide instructions to MSS personnel to accomplish this task.
12.4.2 Safe Tug/SC	Avionics	• Provide RF comm link & controls to deactivate guidance & navigation and flight control subsystems. • Provide RF comm link & control to safe ACPS. • Send C&W signal to Orbiter.
	Procedure	Same as 12.4.1

Rev. A

FUNCTION FLOW BLOCK NO. 12.5	FUNCTION TITLE: Rotate Adapter & Activate Elements to Accept Tug	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.5.1 Ready Tug deployment adapter	Avionics	• Provide controls and instrumentation to perform adapter readiness functions: • Umbilical panels in retracted position. • Tug-adapter latches in retracted position. • Power available to drive mechanism • Relay status to ground stations. • Transmit C&W data.
	Procedures	• Provide instructions to flight crew to conduct deployment adapter readiness checkouts.
	Structure/ Mechanical	• Provide deployment adapter to accept Tug.
12.5.2 Verify adapter position & rotate if required	Avionics	• Provide controls & instrumentation to rotate deployment adapter to position for accepting Tug/SC. • Relay status to ground station.
	Structure/ Mechanical	• Provide drive mechanism and locking device to rotate adapter and lock adapter at preset position.
	Procedure	• Perform adapter rotation operation. • Visually inspect adapter for docking readiness.

Rev. A

FUNCTION FLOW BLOCK NO. 12.6	FUNCTION TITLE: Maneuver Tug/SC into Adapter	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.6 Maneuver Tug/SC into adapter	Avionics	• Provide instrumentation & communication for Orbiter crew to monitor & control Tug safety status. • Relay status to ground station.
	Procedure	Provide instructions to Orbiter crew to accomplish these tasks.
	Structure/ Mechanical	• Continue to provide attach fittings for RMS end effectors. • Provide indexing mechanism to ensure proper alignment of Tug to deployment adapter for mating.

Rev.

FUNCTION FLOW BLOCK NO. 12.7	FUNCTION TITLE: Remate Electrical Umbilical Panels	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.7.1 Latch deployment adapter to Tug	Structure/ Mechanical	Continue to provide fittings to mate with RMS end effectors. Provide fittings to mate with deployment adapter latches.
	Avionics	• Provide control capability in Orbiter to activate Tug-to-adapter latches. • Monitor status of latch operation. • Relay status to ground control.
	Procedure	Provide instructions to flight crew to accomplish these tasks.
12.7.2 Remate electrical umbilicals NOTE: Umbilical remate may be accomplished concurrent with Tug adapter latching in 12.7.1.	Structure/ Mechanical	Same as 12.7.1, plus: Provide mechanism to remate electrical disconnect umbilicals.
	Avionics	• Provide controls & instrumentation to activate and monitor umbilical remate. • Provide necessary power. • Relay status to ground.
	Procedure	Same as 12.7.1

Rev. A

FUNCTION FLOW BLOCK NO. 12.8	FUNCTION TITLE: Safe Tug/SC for Stowage	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.8 Safe Tug/SC for stowage	Avionics	• Provide transfer switch from Tug power to Orbiter power. • Provide for deactivation of fuel cell power system. • Provide controls to safe all Tug subsystems. • Monitor Tug status and relay to ground station.
	Structure/ Mechanical	• Continue to provide fittings to mate with RMS end effectors and deployment adapter latches.
	Procedure	• Maintain programmed vehicle orientation & attitude during safing operations. • Provide instructions to initiate safing operations.

Rev.

FUNCTION FLOW BLOCK NO. 12.9	FUNCTION TITLE: Rotate Tug into Payload Bay & Secure	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.9.1 Retract Tug into Payload Bay	Structure/ Mechanical	Continue to provide fittings to mate Tug with deployment adapter latches. Provide support fittings to mate with Orbiter support points.
	Avionics	• Provide controls & power to activate & operate adapter rotation drive. • Provide instrumentation & DMS display capability to verify status of drive mechanism. • Provide communication link to transmit status to ground station. • Provide CCTV capability to visually monitor operation.
	Procedure	Provide instructions to Orbiter crew to maintain orientation and attitude while accomplishing these operations.

Rev. A

FUNCTION FLOW BLOCK NO. 12.10	FUNCTION TITLE: Configure Tug/SC for Entry Flight	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.10 Configure Tug/SC for entry flight and remate fluid umbilicals	Avionics	• Provide controls & sensing system for • Activating purge bags He purge • Maintaining 16 psia pressure in MPS propellant tanks. • Maintaining 0.5 to 1.5 psia pressure in purge bags. • Display status at MSS/PSS. • Relay status to ground stations. • Provide program to purge MPS liquid hydrogen tank and lines. • Provide instrumentation to monitor Tug subsystem status.
	Structure/ Mechanical	Maintain primary support for Tug and deployment adapter. Provide capability to reconnect fluid umbilicals.
	Fluids	• Provide helium gas, storage, flow controls & lines for purging MPS LH_2 tank and for purging umbilical panel & MPS purge bag. • Provide He gas, storage, flow control and lines for MPS tank purge bag. • Provide He gas system to pressurize MPS LH_2 tank to 16 psia. • Provide vent system to maintain 16 psia pressure in MPS tanks.
	Procedure	Provide instructions for flight crew to accomplish/monitor these functions.

Rev.

FUNCTION FLOW BLOCK NO. 12.11	FUNCTION TITLE: Verify Tug/SC Status for Entry Flight	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.11 Verify Tug/SC status	Structure	Continue to provide primary support for Tug & deployment adapter.
	Fluid	Continue to provide purge & vent lines and disconnects as in 12.10.
	Avionics	• Provide instrumentation and hardwire C&W monitor & control for Orbiter crew safety. • Transmit status data to ground control and receive confirmation of Tug/SC safe condition.
	Procedure	Provide instructions to flight crew to monitor Tug status and relay to ground stations.

Rev.

FUNCTION FLOW BLOCK NO. 12.12	FUNCTION TITLE: Tug/SC C&W Monitor & Control	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
12.12 Tug/SC C&W monitor & control	Avionics	• Same as 12.11
	Fluid	• Continue to provide LH_2 & LO_2 tank vent & purge line capability. • Provide purge bag vent lines.
	Structure/ Mechanical	• Provide support fittings compatible with Orbiter support locations, surface details & loads necessary to react loads associated with entry and landing. Note: Entry and landing loads for post abort (RTLS) landing must consider LH_2 weight.
	Procedure	Provide instructions for flight crew to monitor & control C&W displays during entry and landing.

Rev.

2.1.6 FLIGHT OPERATIONS-ABORT TERMINATION. The first level flight operations-abort termination function flow diagram is shown in Figure 2-8. This flow was derived by Convair based on data in the Baseline Tug Flight Operations (Reference 2) document and the Tug Operations and Payload Support Study (Reference 3) final report. It covers all activities associated with flight mission abort terminations initiated for return-to-launch-site (RTLS), predeployment on-orbit Tug/Spacecraft abort, and postdeployment Tug/Spacecraft abort conditions. The related functional interface requirements data sheets follow the flow diagram.

C.2

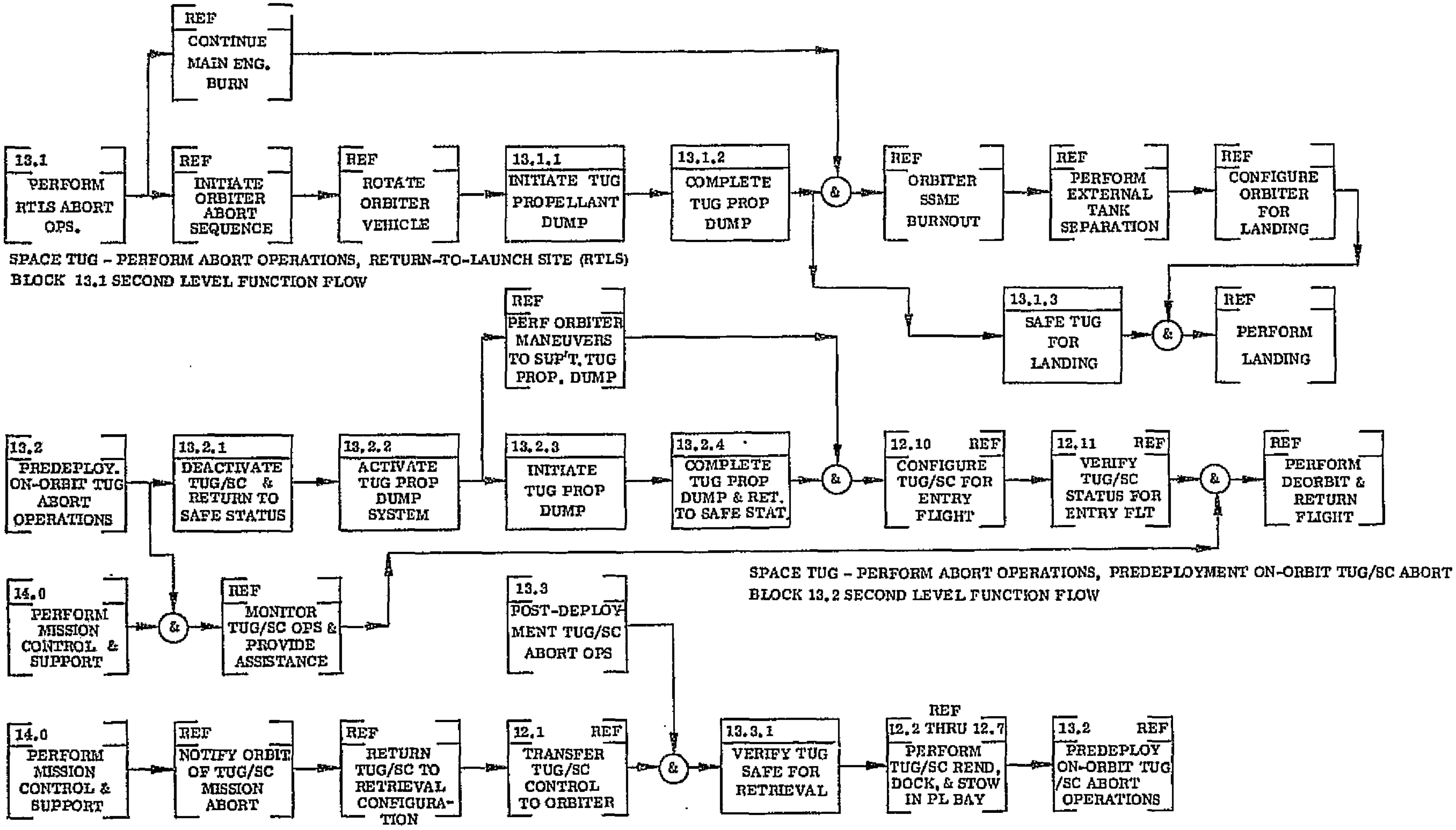

Figure 2-8. Space Tug, Perform Abort Operations, Post-Deployment Tug/SC Abort; Block 13.3, Second-Level Functional Flow

FUNCTION FLOW BLOCK NO. 13.1.1	FUNCTION TITLE: Initiate Tug Propellant Dump	
	CONFIGURATION: All	Sheet 1 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.1.1.1 Activate data management subsystem and propellant dump sequence Note: Recommended RTLS propellant dump includes dumping both LH_2 and LO_2 through dump lines in Orbiter. LO_2 and LH_2 are dumped concurrently with Orbiter applying retrograde thrust.	Fluid	• Provide dump lines which will enable simultaneous dumping of LO_2 and LH_2 (~50,000 lb) within 300 seconds. • Provide pressurization gas, storage, lines and controls to provide pressure head (not to exceed flight pressure) for expediting dumping process. • Provide dump line, controls and interface panels from Tug to Orbiter.
	Avionics	• Provide automatic sequences for LO_2 and LH_2 propellant dump after initiation of dump procedure by Orbiter crew. • Provide program stored in Tug DMS to perform dump operation automatically. • Provide backup program in Orbiter. • Provide instrumentation and lines to initiate and monitor dump progress. • Relay abort status data to ground station. • Provide electrical power.
	Procedure	• Provide instructions to include Tug RTLS abort dump operations with composite Shuttle RTLS abort operations. • Initiate Tug propellant dump.
	Structure	• Provide support/restraint for Tug/deployment adapter/spacecraft compatible with Orbiter support locations.

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FUNCTION FLOW BLOCK NO. 13.1.1	FUNCTION TITLE: Initiate Tug Propellant Dump	
	CONFIGURATION: All	Sheet 2 of 2

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.1.1.2 Monitor RTLS propellant dump operation	Fluid	• Same as 13.1.1.1
	Avionics	• Same as 13.1.1.1
Note: RTLS abort is expected to be a busy period for Shuttle flight crew and the two flight crew members are expected to be supported by ground controllers in monitoring Tug dump process.	Procedure	• Orbiter crew relay Tug abort process data to ground station. • Mission control provide assist by monitoring abort process and maintaining voice contact with Orbiter crew. Also, provide technical assistance by advising Orbiter crew of dump operation and corrective actions to be taken for anomolies.

Rev.

FUNCTION FLOW BLOCK NO. 13.1.2	FUNCTION TITLE: Complete Tug Dump	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE

13.1.2 Complete Tug dump	Fluid	• Provide sensors to detect propellant depletion.
		• Provide controls to halt dump process.
		  • Stop LO_2 and LH_2 abort pressurization
		  • Close drain/dump lines
		  • Open positive g vents

	Avionics	• Provide program to safely shut down dump operation after receiving depletion signal. • Provide backup program in Orbiter to safely terminate dump operation. • Provide instrumentation and data link to transmit status data to Orbiter. • Monitor Tug propellant dump and relay status data to ground station. • Provide electrical power.
	Procedural	Same as 13.1.1
	Structure	Same as 13.1.1

Rev. A

FUNCTION FLOW BLOCK NO. 13.1.3	FUNCTION TITLE: Safe Tug for Landing	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

PA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.1.3 Safe propulsion subsystem	Fluid	Same as 13.1.2 • Maintain helium purge of purge bag for LO_2 and LH_2. • Provide sensors, He gas supply and vent system to maintain LO_2 and LH_2 tank pressure at transport press (~16 psia) • Provide helium purge system of panels andlines.
	Avionics	• Provide instrumentation, DMS and data lines to inert main propellant system and abort pressurization system. • Provide data link to Orbiter to transmit Tug status data and relay to ground stations.
	Procedural	• Provide instructions to perform this function.
	Structure	Same as 13.1.1

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FUNCTION FLOW BLOCK NO. 13.2.1	FUNCTION TITLE: Deactivate Tug/SC and Return to Safe Status CONFIGURATION: All — Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.2.1 Deactivate Tug/SC and return to safe status Note: As shown in Block 11.0, this mission abort occurs during pre-deployment Tug/SC activation and checkout. Ground control during pre-deployment senses either Tug or SC malfunction which necessitates mission abort.	Avionics	• Provide data link to Orbiter, DMS, and data lines to subsystems to receive ground control command to terminate activation and checkout procedure. • Provide DMS and data lines to subsystems to passivate all subsystems except DMS. • Provide instrumentation and data link to Orbiter to transmit Tug status to Orbiter and relay to ground station. • C&W data transmittal.
	Procedure	• Provide instructions to perform this operation. • Orbiter crew will relay commands from and status data to ground stations, and • Monitor caution and warning to ensure Orbiter safety. Mission Control: • Make determination to abort mission. • Provide commands to Orbiter and Tug to abort mission and return Tug/SC to safe status. • Transfer Tug/SC control to Orbiter.
	Structure	• Provide support/restraint for Tug/deployment adapter/spacecraft during abort operations sequence.
	Fluid	• Provide lines and gas supply to deactivate fluid systems and prepare for propellant dump. Includes interface panels between Tug and Orbiter for main tank vent.

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FUNCTION FLOW BLOCK NO. 13.2.2	FUNCTION TITLE: Activate Tug Propellant Dump System	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.2.2.1 Settle propellants in Tug tanks	Fluid	• Provide for switching from zero g vent to positive g vent.
	Avionics	• Provide controls to perform transfer of propellant tank vent system. • Provide instrumentation and data link to transmit status data to Orbiter.
	Procedure	• Provide positive (+x) thrust (OMS or RCS engine firing) to settle Tug propellants in tanks. • Continue to relay Tug status data to ground station.
	Structure	Same as 13.2.1
13.2.2.2 Initiate tank pressurization	Fluid	• Provide abort pressurization system. • Provide drain/dump lines, controls and interface panels. Dump lines to be routed to aft end of Orbiter and oriented axially to provide positive thrust.*
	Avionics	• Provide DMS and lines to initiate pressurization of propellant tanks (~20 psia). • Provide instrumentation and data link to transmit Tug status to Orbiter and relay to ground station.
	Procedure	• Transmit command to initiate dumping procedure. • Perform programmed orientation and attitude maneuvers. • Continue relaying status data to ground stations.
	Structure	Same as 13.2.1
		*If insufficient Orbiter RCS or OMS propellant is available for settling.
		Rev. A

FUNCTION FLOW BLOCK NO. 13.2.3	FUNCTION TITLE: Initiate Tug Propellant Dump	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

PA Tug-Orbiter   ___ Tug-Payload   ___ Tug-Payload-Orbiter

___ Tug-GSE   ___ Tug-Facility

M = Mechanical Handling   P = Propellant/Pressurant/Fluid   A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.2.3 Initiate dump	Fluid	• Provide dump flow control starting with trickle flow to chill lines and increasing flow to full flow condition. • Provide pressurization system for tanks.
	Avionics	• Provide instrumentation DMS and lines to control dump process and transmit Tug status data to Orbiter and relay to ground station.
	Procedural	Same as 13.2.1, plus • After dump process reaches full flow, terminate OMS or ACS thrusting. Assume propellant dumping of LH_2 and LO_2 will provide sufficient thrust to maintain propellant settling. • Maintain programmed orientation and attitude. • Continue relay of status data to ground station. • Transmit C&W data.
	Structure	Same as 13.2.1

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FUNCTION FLOW BLOCK NO. 13.2.4	FUNCTION TITLE: Complete Tug Propellant Dump & Return to Safe Status	
	CONFIGURATION: All	Sheet 1 of 1

INTERFACE:

MPA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.2.4 Complete Tug propellant dump and return to safe status Note: LH_2 tank purge will be accomplished after landing as part of abort post-landing operations.	Fluids	Same as 13.2.1, plus • Provide sensors to detect propellant depletion in LH_2 and LO_2 tanks. • Provide controls to terminate dump process . Shut down LH_2 and LO_2 tank pressurization. . Close drain/dump lines. . Purge lines and panels. • Provide helium supply and interface lines to reinitiate LH_2 tank purge bag purge flow for entry and landing.
	Avionics	• Provide program to safely shut down dump operation of LO_2 and LH_2 tanks after receipt of sensor signals. • Provide program to configure Tug propulsion system for return-to-ground mode. • Monitor status and provide to Orbiter for Orbiter crew and for relay to ground station.
	Procedure	Same as 13.2.1, plus • Monitor dump process, verify completion and return Tug to safe condition. • Continue to relay status to ground station.
	Structure	Same as 13.2.1

Rev.

FUNCTION FLOW BLOCK NO. 13.3.1	FUNCTION TITLE: Verify Tug Safe for Retrieval	
	CONFIGURATION:	Sheet 1 of 1

INTERFACE:

PA Tug-Orbiter ___ Tug-Payload ___ Tug-Payload-Orbiter

___ Tug-GSE ___ Tug-Facility

M = Mechanical Handling P = Propellant/Pressurant/Fluid A = Avionics

TASK NUMBER & TITLE	SYSTEM	FUNCTIONAL INTERFACE
13.3.1 Verify Tug Safe for Retrieval	Avionics	• Provide communication, DMS, G&N, ACS to . Establish RF communication link with Orbiter. . Stabilize and orient Tug/SC. . Perform commands received from Orbiter. . Transmit status data to Orbiter including: main propulsion system controls, lines and sensors to safe propellant tanks and pressurization system, and attitude control system to perform maneuvers and stabilize Tug/SC.
Note: This abort mode arises after Tug/SC has been deployed and released by Orbiter, but prior to initial Tug main engine burn. Ground control is assumed to be performing a detailed status verification of Tug and SC. During this period, ground control identifies malfunction which results in decision to abort Tug/SC flight mission. Ground control will return Tug/SC to safe status for retrieval by Orbiter.	Procedure	• Provide input to flight crew instructions to: . Establish RF link. . Transmit commands to orient Tug/SC for rendezvous. . Verify Tug/SC subsystems are safe and configured for retrieval. . Relay status data to ground control.

Rev. A

2.2 SAFETY AND RELIABILITY REQUIREMENTS

The NASA Tug requirements document (Reference 4) has been reviewed to identify the safety requirements that are applicable to the Interface Study. Except for the addition of reference to hazards to the public and the ecology, the principal safety requirement remains essentially unchanged from the Space Tug Systems Study (Reference 5). That is, "No single Tug failure shall result in a hazard which jeopardizes the flight or ground crews of the Shuttle, general public, public/private property, and the ecology." It is, of course, of paramount importance that this particular criterion be complied with. In any instance where compliance with this criterion cannot be achieved, the noncompliance and the rationale for noncompliance, must be so noted.

In addition to the above stated principal safety requirement, other safety requirements deemed to be specifically applicable to the Interface Study have been extracted from the requirements document and included in Table 2-1. The "Reference Paragraph" column in this table provides a cross reference between the table and MSFC 68M00039-1 (Reference 4). This five-digit number, followed by a letter or letters, is shown at the top of each table page. Only the letter(s) referring to the number at the column head is included for the remainder of the requirements on each page. Where two or more criteria are grouped into a single requirement, this grouping is so noted by the addition of a paragraph reference(s) in parentheses. The safety requirements have been further categorized in the following manner:

R - Indicates a safety requirement that must be specifically addressed during the study. We must either show how the requirement is reflected in our recommended designs or show specific rationale for any noncompliance.

D - Indicates a safety requirement that can only be satisfied during detail design. The designs developed during the study should, however, contain no feature that would preclude attainment of the requirement during detail design.

I - Indicates a joint safety requirement between the interface subsystems and other Tug/Orbiter/spacecraft systems. We must show how our designs are consistent with the related Tug/Orbiter/spacecraft safety requirements.

These safety requirements are the basis for the safety functional requirements contained in Section 2.3 of this report.

Table 2-1. Safety Requirements Summary

Tug Orbiter Requirements	Reference Paragraph	Category
1. Tug safety data, controls, hardware, safety procedures, etc., that are necessary to prevent damage to and to insure the safety of the Orbiter shall be provided. The safety critical data, displays, and controls shall be capable of being verified functionally.	3.2.6.1.2 f	I
2. Materials, fluids, etc., shall not be released or ejected into the payload bay from the Tug. Venting, relief, and release of material from the Tug shall be through the Orbiter provided vent system. Control of the venting, etc., by the Orbiter for certain mission phases may be required.	l (3.2.6.1.3a4) (3.2.6.1.4a11)	I
3. Redundant equipment having safety implications shall be located away from the primary source to which it provides safety protection or which prevent hazard propagation.	n (3.2.6.1.4a20)	R
4. Where hazards can occur due to the presence or contact of mutually incompatible materials, fluids, electrical potential, etc., such as fuels and oxidizers, these materials, fluids, etc., shall be separated to the maximum possible extent.	o (3.2.6.1.2ah)	R
5. Provisions shall be included for emergency manual release of Tug to Orbiter connections.	t	R
6. Provisions shall be made for remote emergency jettisoning of Spacecraft deploying equipment and antennas as necessary to complete retrieval and stowage operations of the Tug.	u	I
7. Tug shall provide at all times to the Orbiter such information as necessary concerning the status or condition of Tug and Spacecraft systems to ensure safety of Orbiter and crew. Provisions shall also be made for Orbiter override of safety critical Tug and Spacecraft functions during stowage aboard the Orbiter and during Tug deployment and retrieval phases of operations.	v	I

Table 2-1. Safety Requirements Summary, Contd

Tug Orbiter Requirements	Reference Paragraph	Category
8. Provision shall be included for control of all safety critical Tug functions, including attitude and translational position control by Orbiter crew during post-deployment and pre-retrieval operation for Orbiter/Tug separation distances TBD.	3.2.6.1.2 w	I
9. Provisions shall be made to confirm that all safety critical Orbiter/Tug electrical connections, fluid lines, etc., interfaces are securely connected.	x	R
10. Tug deploy/release/retract mechanisms shall not cause a hazard even after a failure has been experienced with that system(s).	ae	R
11. Provisions must be made for verifying readiness of safety critical Tug systems before activation.	af (3.2.6.1.4c5) (3.2.6.1.4d12)	I
12. All mechanical, electrical and fluidic connections between the Tug and Spacecraft and Orbiter shall be fail safe.	ag	R
13. Provisions shall be made for detecting the presence of spilled hazardous fluids or materials during handling or transfer.	ak (3.2.6.1.3a7) (3.2.6.1.4g2)	I
14. Environmental control of the Tug if required shall be provided after propellants/pressurants are loaded until launch.	3.2.6.1.3 a (3)	I
15. Purge provisions shall be available to neutralize propellant leaks during and after propellant servicing and after Orbiter landing.	a (5)	I
16. Ventilation shall be provided under positive pressures for all propellant loading operations to prevent accumulation of hazardous vapors.	a (c)	I
17. Transfer lines shall be purged after the transfer of hazardous fluids.	b (7)	R
18. Integrated checkout and testing of safety critical Tug systems shall be conducted prior to installation in the Orbiter and verified after installation into the Orbiter.	b (15)	I

Table 2-1. Safety Requirements Summary, Contd

	Tug Orbiter Requirements	Reference Paragraph	Category
19.	Tug pressurized systems shall have a maximum operating pressure helium leak check before installation into the Orbiter payload bay and an inert gas leak check before loading propellants.	3.2.6.1.3 b (16)	I
20.	Internal attitude control signal of the Tug shall be capable of being checked for accuracy by the Orbiter crew before release.	c (4)	I
21.	Provisions shall be made to pressurize propellant tanks of Tug to avoid implosion during return flight.	c (7)	R
22.	Tug propellant tank and pressure vessel design factors of safety shall be as specified in Space Shuttle System Payload Accommodations JSC 07700, Vol XIV, Rev. B, December 21, 1973.	3.2.6.1.4 a (1) (3.2.6.1.2r)	R
23.	Pressure vessels and tanks shall conform with and be maintained under a fracture mechanics control program.	a (2)	R
24.	Pressure lines and vessels shall be clearly coded to identify contents, capacity and operating pressure.	a (3)	D
25.	Flexible sections of pressure hose disconnects shall be restrained so that a failure will not cause damage to adjacent equipment or injury to personnel.	a (5)	R
26.	A structural interface shall be provided between the Tug and the Orbiter payload bay support points that transmits the Tug and Spacecraft loads into the Shuttle structure with a 25% margin of safety under the most adverse Shuttle design loads, excluding crash loads which are ultimate.	a (7)	R
27.	Provision shall be made to detect incipient failures of tanks containing hazardous fluids or high pressures to the greatest extent possible.	a (8)	R
28.	A redundant relief capability shall be provided for the Tug tanks which automatically limits the maximum pressure.	3.2.6.1.4 a (10) (3.2.6.1.4a18)	I
29.	Tug propellant drain and vent interface with the Orbiter shall permit main propulsion system propellant venting, and emergency detanking (whether Orbiter is in horizontal or vertical attitude) until lauch commit, with the Orbiter payload bay doors opened or closed and latched.	a (12)	R

Table 2-1. Safety Requirements Summary, Contd

	Tug Orbiter Requirements	Reference Paragraph	Category
30.	A capability shall be provided for the Orbiter crew to dump main propellant Tug fluids and vent Tug pressurants overboard within the time constraints imposed by an abort situation. This capability shall be available with the payload bay either open or closed.	3.2.6.1.4 a (13) (3.2.6.1.4a18)	R
31.	Tug cryogen tank thermal protection systems shall be designed to minimize (below ignition regimes) accumulation of flammable fluids resulting from propellant system leakage.	a (17)	I
32.	Any Tug supplied deployment/retrieval system shall provide positive control of the Tug movements during translation out of or into the payload bay. It shall be designed for fail operational/fail safe operation or shall be jettisonable to preclude exceeding the Tug stowage envelope.	a (19) (3.2.6.1.2t) (3.2.6.1.2u)	R
33.	Tug fluid fill and drain umbilical disconnects shall have positive sealing at disconnect. Provisions shall be made to prevent pressure buildup in the system.	a (21) (3.2.6.1.4a6)	R
34.	Leakage sources of the Tug or its equipment shall be minimized by use of all welded or brazed construction where practical.	a (22)	D
35	Components and assemblies selected for the Tug shall be marked or tagged to identify their manned-mission application.	a (24)	D
36.	Cleanliness requirements and fluid contamination for propellants and propellant systems shall be controlled and monitored to assure that the STS safety is not jeopardized.	a (25)	I
37.	Hypergolic propellant tanks, fuel and oxidizer, shall be pressurized from separate pressure sources.	a (26)	I
38.	A leak sensing system shall be utilized to detect leaks at the deployment adapter interface.	a (27)	R
39.	Tug propulsion system start sequence logic status and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management Interface. Transmissions shall be through hardwire while within the Orbiter bay but once outside it may be transmitted directly from the Tug.	b (5)	I

Table 2-1. Safety Requirements Summary, Contd

	Tug Orbiter Requirements	Reference Paragraph	Category
40.	Systems containing fluids that are subject to decomposition through contamination or loss of passivation (such as monopropellants) shall be safed by appropriately sized and located vents for the worst case decomposition rate.	3.2.6.1.4 b (5)	I
41.	Message signals for Tug system, by hardwire and RF telemetry, shall be provided at the Shuttle Data Management System Interface. Measurements shall include Tug latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications. This information should also be available prior to retrieval.	c (1)	I
42.	Tug critical command and control circuitry shall be designed to be fail operational/fail safe as a minimum.	c (3)	I
43.	Tug batteries shall have the case vented through relief valves into Orbiter overboard venting system.	d (2)	R
44.	Electrical umbilical disconnects between the Orbiter and the Tug and between the Tug and Spacecraft shall be separated from hazardous fluid disconnects, shall be qualified as explosion proof, and shall not have power applied during disconnect.	d (5)	R
45.	Power circuits shall be separated from critical pyrotechnic circuits within a cable or wire bundle.	d (6)	D
46.	Tug structure shall be grounded to Orbiter structure to prevent electrostatic charge buildup and an electrical shock hazard. Within the Tug grounding shall be such as to preclude an electrical shock.	d (7)	R
47.	Safety critical electrical and electronic components shall be potted, hermetically sealed or similarly protected against the effects of liquid leakage, moisture condensation, vibration and arcing contacts.	d (8)	D
48.	Capability shall be provided for static discharge between Tug and Orbiter and between the Tug and Spacecraft.	d (9)	R

Table 2-1. Safety Requirements Summary, Contd

	Tug Orbiter Requirements	Reference Paragraph	Category
49.	Positive identification and adequate protection shall be provided for identical safety critical switches. Identical safety critical switches shall not be located in close proximity to each other.	3.2.6.1.4 d (13)	D
50.	Tug shall have a means of shutting off its electrical power under emergency conditions.	d (15)	I
51.	Electrical wiring must not be routed against or around sharp edges.	d (16)	D
52.	Electrical wiring must not be in contact with flammable fluids.	d (17)	D
53.	Electrical circuits which will be cut by guillotine cutters must be deadfaced.	d (18)	I
54.	Provisions shall be included for Tug caution and warning functions which will provide both audible and visual warning to Orbiter personnel of hazardous situations while the Tug is in the Orbiter payload bay or being deployed.	d (19)	I
55.	Fuel cells are to be activated only after TBD distance separation from the Orbiter.	d (20)	I
56.	Only GN_2 shall be permitted to be dumped into Orbiter payload bay from the Tug and then only under controlled conditions.	g (1)	R
57.	Artificial sources of radiation with the Tug shall be shielded, oriented, otherwise limited to prevent exceeding flight crew dosimetry requirements as established by the NASA radiation constraints panel. Compliance with critical equipment radiation requirements shall also be maintained.	g (3)	R

2.3 SYSTEM FUNCTIONAL INTERFACE REQUIREMENTS

The functional interface requirements identified in Section 2.1 and the safety requirements of Section 2.2 have been collated and summarized by Tug system in this section. The four major groupings are:

Avionics System Functional Interface Requirements, pages 2-84 through 2-94
Fluid Systems Functional Interface Requirements, pages 2-95 through 2-99
Structure System Functional Interface Requirements, pages 2-100 through 2-103
Procedural Functional Interface Requirements, pages 2-104 through 2-112

All mechanism functional interface requirements have been included within their associated primary system functional interface requirements tabulation. For example, fluid umbilical panels are listed under the fluid system and structural latching/releasing devices are listed under the structure system.

Within each system/procedural area, functional interface requirements are arranged in Tug mission operational sequence: post-landing operations (Block 4.0), Tug/Spacecraft/Orbiter mate and checkout (Block 2.0), launch operations (Block 1.0), flight operations (Blocks 11.0 and 12.0), and flight operations abort (Block 13.0). Safety and reliability criteria based on the safety requirements summarized in Section 2.2 have been added to provide a complete composite matrix of all functional interface and safety requirements for Tug systems. The function flow diagram reference block number will permit ready identification and evaluation of the potential systems impact of changes in Tug operations plans or sequences.

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SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
	GROUND OPERATIONS	
5.1	Provide instrumentation, data management capability to collect and display power and purge gas data at the MSS/PSS. This will require hardwire link between Tug-deployment adapter and Orbiter aft bulkhead panel to MSS/PSS. May require interface thru Orbiter to ground position for ground power/gas supply.	• Incorporate purge gas minotors with capability to measure safe concentrations of H_2, O_2 and N_2H_4. • Incorporate Tug tank pressure monitors. • Incorporate insulation purge gas monitors for H_2&O_2 main tanks. • Monitoring instrumentation & wiring to be dual redundant and fail safe (i.e., failure of the monitor system, in itself, will not cause a hazardous condition. • Safety critical data, displays & controls shall be capable of being verified functionally. • Electrical umbilical disconnects shall be separated from hazardous fluid disconnects.
5.1A (RTLS)	Provide same capability as above, plus additional capability to control and monitor ACPS drain and propellant purge operations including interface thru Orbiter to ground control station.	• Provide capability to complete LH_2 dump prior to SSME burnout. • Provide capability to purge LH_2 dump line with helium after dump is completed.
5.1A (AOA/ATO)	Provide same capabilities as in 5.1 and 5.1A (RTLS) above.	• Same as 5.1 and 5.1A

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
5.2	Provide same basic capability as in 5.1 above, to monitor tank and purge bag condition at MSS/PSS during Tug removal from Orbiter. Also provide interface receptacles/connectors to facilitate making or breaking avionics interfaces for Tug removal (installation) operations. Locate panels for ease of access in either horizontal or vertical install-remove operations.	• Interface receptacles/connectors to be unpowered at time of disconnect. • Interface receptacles/connectors to be connected only with Tug in a completely 'safed' state; i.e., no propellants nor reactants on board, all pyrotechnic safed.
5.3	Provide hardwire interface from Tug thru deployment adapter to Orbiter MSS/PSS to record and store Tug flight performance data and a means to readily remove (physically or electronically) this stored data with the Tug in the Orbiter payload bay following landing and safing operations.	All safety critical functions to be monitored/controlled by hardwire interface. Monitor/control to be dual redundant & fail safe.

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SYSTEM: AVIONICS		Sheet 3 of 11
SUBSYSTEM:		
Reference Function Block Nr.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
2.1, 2.2 (2.1.6 and on)	Provide interface panels/receptacles for all Tug-Orbiter avionics interface connections. Hardwire will run from Tug thru the deployment adapter to panel locations on Orbiter payload bay aft bulkhead, thence to ground disconnect panels on the Orbiter mold line and/or to MSS/PSS panels as may be required for C&W display. Interface panels must be located for ease of access during horizontal installation/removal at OPF (this task) and vertical installation/removal (Ref. Task 1.3.5) at launch pad.	• Provide interconnecting ground between work platforms, Tug/Spacecraft & Orbiter. • Provide capability to ensure ground/ Orbiter power off before connecting Tug/Spacecraft disconnects.
2.3	Provide interface panels as in 2.1 & 2.2 plus required instrumentation and data management capability to collect and display critical Tug/SC caution & warning parameters at a point external to Tug during Shuttle buildup and transfer to launch pad. Location should probably be in one of the MLP rooms with available access during these operations. Instrumentation and data management should be limited to normal flight capability and not require additional non-flight hardware. Provide necessary software for condition monitor and display tasks.	Instrumentation & data management capability to include capacity for processing data to permit safe "backout" from any emergency condition.
1.1	Continue to provide interface panels, instrumentation and data management capability as in 2.1 - 2.3. In addition, provide instrumentation and data management capability to monitor and verify status of Tug/SC propulsion and avionics systems during Shuttle pad operations. Data display should be at MSS/PSS and ground control stations. Provide necessary software to interface with launch pad LPS.	• Establish clear sequence control transfer between ground & Orbiter control, plus ground control master override in case Orbiter crew evacuation is required.

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
1.2	Continue to provide interface panels, lines, instrumentation and data management capability as in 2.1 - 2.3 and 1.1 above to support Tug propellant loading during final countdown. Must monitor and control LO_2, LH_2, He, and ACPS reactant tank fluid levels, pressures, venting and topping and display data at ground control stations. Provide software required to interface with LPS.	• Propellant leak sensors to be provided in payload bay & in purge vent outlets (containment membrane purge & fluid interface panel purge).
1.3	Continue to provide all interface capabilities listed in 2.1, 2.2, 1.1 and 1.2 plus added capability to control, monitor and display required data at ground stations for initiating backout procedures including payload changeout. Depending upon time backout is initiated, it may be necessary to display data at MSS/PSS locations.	• Include umbilical disengagement backout/safing capability. • Provide capability to automatically control sequencing of any safety critical operations which are sensitive to their order of initiation. • Safety critical functions monitor & control shall be fail operational-fail safe for all ground & airborne interface equipment.
1.3A	Provide all avionics interface capability listed or referenced in Task 1.3, plus additional capability to control and monitor total propellant and pressurant drain, purge and/or vent. Display and control will be from remote ground control location and require LPS software interface.	
1.4	Continue to provide avionics interface capability established in 2.1, 2.2, 1.1 and 1.2 during Orbiter task of closing cargo bay doors to monitor Tug status during this and other Orbiter tasks at launch pad. Incorporate LPS interface and software as required.	
1.5	Continue to provide avionics interface capabilities established in 2.1, 2.2, 1.1 and 1.2. Provide capability to control, monitor and verify all Tug system status data on both MSS/PSS and ground control launch center, including necessary LPS hardware/software interface.	Rev. A

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
	FLIGHT OPERATIONS Provide control & monitoring capability to automatically perform the following at main engine ignition or Shuttle first movement: • Close LH_2&LO_2 tank vent valves • Terminate He purge • Open purge bag vent valves • Provide necessary software to accomplish these functions. • Provide power to Tug during ascent flight. (Note: Alternative is to operate Tug fuel cells during ascent and provide required cooling capability - see fluid system). During powered flight, automatically: • Open LO_2&LH_2 vent valves at 200 sec or ≥ 300,000 ft alt. (Provide manual override at C&W panel). During Shuttle orbit • Transmit Tug status to ground stations. Baseline assumes TDRS for NASA missions which provides 90% coverage at 160 nm orbit and SGLS 11 RTS for DOD which provide 15% orbit coverage. • Activate zero-g vent systems and close positive G vent valves.	• Tank containment membrane helium purge to be "on" during all atmospheric flight profile with overboard vent from the Orbiter. • Provide manual override capability from Orbiter crew compartment C&W panel. Requires interface lines, panels, disconnects from SC/Tug thru deployment adapter to payload bay aft bulkhead to crew compartment. C&W monitor & control panel in crew compartment will be inter-connected with Orbiter flight crew displays & controls, aural alarm & illuminated talk back. In addition, these data must be fed thru Orbiter communication system and relayed to ground station. Rev. A

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SUBSYSTEM:	

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
11.2	Continue to provide Tug/SC status data to & receive commands from ground control via Orbiter communication system interface. Provide software capability to accomplish predeployment activation and checkout. Receive Tug go-no go signal from ground stations. crew compartment.	• Maintain Orbiter manual override capability on safety critical items.
11.3	Continue to provide avionics interface identified in 11.1 & 11.2 with additional capability to: • Provide controls to initiate, operate monitor and stop deployment adapter rotation drive mechanism. • Provide status of same to ground stations thru Orbiter communication system. • Provide controls to release Tug forward attachment latches. • Provide lights & CCTV to inspect Tug/SC prior to deployment. • Provide electrical power to accomplish the above.	• Tug deploy/release/retract mechanisms shall be designed such that they will not generate a hazard, even after a failure has been experienced with that system. • Capability of Tug jettison via EVA shall be designed into the deploy/release/retract mechanisms.
11.4 & 11.5	Continue to provide avionics interface identified in 11.1 - 11.3 with additional capability to: • Provide controls & data management system to open non-thrust H_2&O_2 vents. • Disable zero-G vents. • Activate fuel cell (if not already on) and change over to internal power. • Provide data link to update G&N state vector. • Continue to provide RF data/command link to/from ground sta. • Provide additional state vector update data.	• Controls used in operation of H_2&O_2 vents shall be hardwired & shall be designed ach that control of the vent function is fail operational-fail safe.

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
11.6	Continue to provide Tug/SC avionics interface capability identified in 11.1 - 11.5 and: • Initiate fluid umbilical disconnect retraction & display status at MSS/PSS and relay to ground sta. • Release deployment adapter latches & display status at MSS/PSS & relay to ground station.	• Umbilical disconnects to be capable of being manually disengaged via EVA in the event of disconnect malfunction. • Deployment adapter latches to be capable of being manually disengaged in event of latch malfunction.
11.7	Continue to provide avionics interface capability identified in 11.1 - 11.6 and: • Initiate withdraw Tug from deployment adapter, monitor status, and display at MSS/PSS & relay to ground station. • Disconnect electrical umbilical & switch to RF link. • Provide data link to enable ACS.	• Safety critical monitor & control functions that are normally hardwired shall be capable of being shifted to RF link just prior to withdrawing Tug from adapter.
11.8	Continue to provide avionics interface identified in 11.1 - 11.7, and: • Provide controls, communication & DMS to signal ACS operation once Tug/Orbiter at a safe separation distance. (RF link from Tug to Orbiter).	
12.1	Re-establish RF link between Tug/SC & Orbiter for transfer of control from Ground to Orbiter. Provide: • Communication system compatible with STDN & AFSCF networks & compatible with Orbiter and ground stations. • Provide Tug/SC with capability to receive 2.4 Kbps information rate & total 8 Kbps encoded command data with BER of 10^{-5}; capability to transmit 16 Kbps TM data to Orbiter.	• Provide capability to determine status of safety critical systems. • ACS fail operational/fail safe status • Electrical power fail operational/fail safe status • Communication/control

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Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
12.2	Maintain RF link from 12.1 and: • Provide transponder compatible with Orbiter rendezvous radar. • Capability to receive commands and compute signals for ACS. • Transmit status/C&W data to Orbiter. • Provide status data relay to ground station.	
12.3	Maintain Tug-Orbiter RF link from 12.1, and: • Provide G&N, DMS & flight control to maintain commanded orientation & position. • Provide controls to deactivate transponder on Orbiter command. • Transmit/receive & implement commands for positioning Tug in preferred docking attitude.	• Verify safety status of Tug (S/C) & transmit to Orbiter.
12.4	Maintain RF link from 12.1, and: • Command ACS to stabilize Tug-S/C for RMS end effector mating. • Deactivate ACS, G&N & flight control system.	
12.5	Provide controls, instrumentation to check and/or perform deployment adapter readiness functions & rotate to remate position if required. Includes: • Umbilical panels in retracted position. • Tug-adapter latches in retracted position. • Power available to drive mechanism if required • Adapter position monitor. • Relay status to ground control sta.	

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Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
12.6 - 12.7	Provide controls in Oribter to activate adapter latches & monitor latching action. Provide control to remate electrical umbilical/disconnects & monitor status. Relay status to ground stations. Provide electrical power as required.	• Provide instrumentation & communication to monitor & control Tug/SC safety & status. Relay status to ground control stations.
12.8	Using remated electrical umbilicals: • Provide switch for power transfer from Tug power to Orbiter power. • Provide for deactivation of fuel cell power system. • Continue to monitor Tug/SC system status & determine that it is safe to rotate Tug into cargo bay. • Relay status to ground stations.	• Tug/adapter latches & interface panels shall be capable of being remated manually via EVA in the event of component malfunction. • Provide capability to continuously monitor status of Tug/SC safety critical functions during rotation into payload bay. • Ref. 11.3/11.4 - Provide capability to jettison Tug/spacecraft if remate & checkout not possible.
12.9	• Provide controls to operate & monitor adapter rotation drive mechanism. • Provide electrical power for drive mechanism. • Provide lights & CCTV to visually monitor retraction operation. • Verify all latches in proper position before retraction & properly latched after Tug is rotated into cargo bay. • Relay status of operation to ground control stations.	
12.10	To configure Tug/SC for entry flight: • Provide controls to remate fluid disconnects. • Activate purge bag He flow and maintain 0.5 to 1.5 psia pressure in purge bag. • Maintain 16 psia in main propellant tanks. • Display all Tug/SC system status at MSS/PSS panels & relay to ground stations.	• Reverify hardwire safety control/monitor lines are operable for entry. • Reinitiate tank containment membrane He purge with Orbiter overboard vent.

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
12.11-12.12	Continue to monitor status, display on C&W panels & relay to ground control stations during entry flight & for landing & landing rollout.	Provide capability to verify Tug/SC status for entry flight, using hardwire interface path: • Provide instrumentation and readout for C&W monitor & control for Orbiter crew at MSS/PSS & pilot C&W panel. • Relay status to ground control station.
13.1	To initiate Tug propellant dump for RTLS abort mode: • Provide software and avionics interface lines & disconnects to automatically sequence LO_2 and LH_2 dump after initiation by Orbiter crew. • Provide program in Tug DMS & backup program in Orbiter to accomplish propellant dump.	• Provide capability to monitor dump operation & display status at MSS/PSS &Orbiter pilot C&W panels and relay status to ground stations. In addition to above, use same interface & programs to: • Provide for dump operation safe shutdown. • Display status on Orbiter C&W panels & relay to ground stations. In addition to above, use same interface & programs to safe Tug propulsion system for landing by: • Providing instrumentation & controls to inert LO_2 and LH_2 system. • Display status on Orbiter C&W panels and relay to ground station.
13.2.1 thru 13.2.4	To deactivate Tug, return to safe status & complete Tug propellant dump associated with predeployment abort (Abort-Once-Around or Abort to Orbit) AOA/ATO:	

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Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
13.2.1 thru 13.2.4 (Cont'd.)	• Provide data link (hardwire) to Orbiter & relay to ground station to receive ground control orders to terminate activation & checkout procedures. • Transfer propellant tank vent from zero-g to normal vent valves. • Initiate pressurization of main propellant tanks to ≈ 20 psia. • Initiate propellant dump by opening valves in dump lines.	• Provide capability to return all systems to safe (passive) status. • Display system status at Orbiter C&W panels and relay to ground stations. • Provide program capability to safely terminate propellant dump after tank fluid level sensors indicate tanks are empty. • Provide program to configure Tug for safe entry and landing.
13.3.1	To deactivate Tug/SC & verify that it is safe for retrieval after deployment & release, but prior to main engine burn: • Provide RF link between Tug & Orbiter & relay from Orbiter to ground stations. • Stabilize & orient Tug. • Display Tug/SC status at Orbiter C&W panels and relay to ground control. Note: This step is in preparation for retrieval in accordance with tasks 12.2 thru 12.7, then propellant dump in accordance with task 13.2 for an AOA/ATO abort termination of the mission.	Status of safety critical functions shall be verified by redundant communication system.

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
5.1	GROUND OPERATIONS • Provide interface panels and lines from LH_2 & LO_2 main tank vent valves through deployment adapter & Orbiter aft bulkhead to dump ports/lines on Orbiter. • Provide interface panels & lines from LH_2 & LO_2 main tank purge bag vents through deployment adapter & Orbiter aft bulkhead to purge bag vent port/line.	• Incorporate purge gas monitors with capability to measure safe concentrations of H_2, O_2 & N_2H_4 in fluid lines, disconnects, purge exhaust & purge vents. • Incorporate pressure sensors in all pressure lines to ensure venting before disconnect. • Duct H_2&O_2 vents to Orbiter overboard vent ports. • Vent Tug batteries into Orbiter overboard vent ports. • Incorporate purge connections as integral part of fill, drain & abort dump equipment. • Purge all propellant lines with helium after drain operations. • Fuel & oxidizer interconnect panels shall be separated to maximum extent possible. • Vent valves on LH_2&LO_2 tanks shall be backed up by redundant vent valves on adapter. • ACPS tank to incorporate safety vent that will vent N_2H_4 external to Orbiter in event of inadvertent N_2H_4 decomposition. • Flexible sections of hose disconnects shall be restrained. • Propellant vent system shall permit vent with Orbiter horizontal/vertical & payload bay doors open or closed.
5.1A (RTLS)	Provide interface panels & lines from main LH_2 & LO_2 tanks and ACPS reactant tanks to permit the following tasks after an RTLS abort landing: • Vent and purge main LH_2 tank. • Purge main LO_2 tank. • Drain & purge ACPS fuel tank. • Purge fuel cells • Vent helium bottles to safe working pressure. • Vent purge bags.	
5.1A (AOA/ATO)	Provide interface panels & lines from main LO_2 & LH_2 tanks and ACPS reactant tanks to permit following tasks after an AOA or ATO abort landing: • Vent & purge main LH_2 tank. • Purge main LO_2 tank. • Vent purge bags. • Drain & purge ACPS fuel tank. • Purge fuel cells • Vent helium storage bottles to safe working pressure.	
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SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
5.2, 2.1 & 2.2	Provide interface disconnect panels/receptacles/devices at deployment adapter and Orbiter aft payload bay bulkhead to permit ready removal (installation) and verification of all Tug fluid systems lines and connections between Tug-Orbiter-ground for: • Main LO_2 & LH_2 fill, drain, vent and purge. • ACPS fill, drain, vent and purge. • Fuel cell purge. • Helium fill and vent. • Purge bag vents	Same as 5.1. • Provide capability to pressure test all fluid fittings with inert gas prior to filling with normal fluids.
2.3	Continue to provide all fluid systems interface lines and panels installed in 2.1 above to support monitoring any Tug fluid system parameters (in conjunction with Avionics) during Orbiter/Shuttle buildup and move to launch pad.	Provide tolerance band warning system to alert personnel to potential/incipient safety critical condition. Provide over-ride response system to respond to warning.
1.1 & 1.2	Continue to provide all fluid system interface lines & panels installed & verified in 2.1 & 2.2 to enable: • Verification of fluid system status in preparation for loading. • Pre-cool, load, monitor and top as required the main LH_2 & LO_2 tanks. • Load and monitor ACPS fuel (N_2H_4) tank. • Pressurize on-board Helium systems and monitor. • Provide main tank purge bag gas and vent lines.	• Same as 2.3. • Establish definite sequence limits, safe hold positions & hold time limits. • Provide interlocks to preclude inadvertent dropout of disconnects during loading through final countdown.

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SUBSYSTEM:		
Reference Function Block No.	**FUNCTIONAL INTERFACE**	**SAFETY/RELIABILITY CRITERIA**
1.3	Provide same basic interface panels & lines as installed in Task 2.1, but configure & locate for ease of access & removal/ reinstallation with Orbiter & Tug in vertical attitude to facilitate either Back-out-Payload changeout or routine payload installation at the launch pad. Payload changeout at launch pad will not normally entail propellant drain. For those instances where it does, see 1.3A (Pad Abort) below.	• Assure that entire changeout can be safely accomplished in the presence of any single failure of an interface component. • Provide purge capability to reduce all potentially hazardous fluids to safe concentrations. Provide means of verifying safe concentration. • Provide capability of assuring that all safety critical venting, pressures, voltages, controls and monitors are continuously operative throughout changeout operation. • Provide means of assuring that all disconnects are non-pressurized, non-energized, and/or do not contain hazardous fluids at time of disconnect. • Provide disconnect covers to prevent contamination. • All seals at fluid disconnects shall be at least dual redundant.
1.3A	Use established fluid interface panels/ lines, provide additional capacity and capability to: • Safely terminate propellant and/or pressurant loading/topping operations. • Drain all loaded propellants (main and ACPS) and vent or depressurize helium system. • Purge propellant tanks as required to attain safe condition for Tug (payload) changeout or return to standby. • Continue main tank purge bag purge/vent operation.	
1.4 & 1.5	Use basic fluid interface lines and panels installed in 2.1 or 1.3 to monitor, top, vent or purge fluid systems as required during payload bay door closing & final prelaunch and countdown operations. Note: In normal pad sequence, propellant loading (Task 1.2) is accomplished during the first hour of the final 2 hour countdown (Task 1.5). Only topping and status monitoring are required during Task 1.5.	Same as 1.1, 1.2 & 1.3 • Provide H_2, O_2 and N_2H_4 detectors in payload bay. Fluid interface panels to be continuously purged with He during propellant transfer. • Fluid interfaces to be capable of being leak tested with He prior to fueling/ pressurizing Tug systems.
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SYSTEM: FLUIDS		Sheet 4 of 5
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
	FLIGHT OPERATIONS	
11.1 & 11.2	Use fluid system interface lines and panels installed in Task 2.1 or 1.3 to: • Provide LH_2 & LO_2 tank overboard vent capability. Closed at Orbiter main engine start or Shuttle first movement and reopened at ≈ 200 seconds or ≥ 300,000 ft. • Provide for both normal & zero-g vent. • Provide for termination of helium purge on Orbiter main engine start or first movement and opening of purge bag vent valves.	Vent system for both LH_2 & LO_2 to be fail safe. Fluid interface to provide emergency vent for N_2H_4 tank. Vent lines on N_2H_4 and LH_2 tanks to be equipped with flame arrestors at vent outlets He purge on tank containment membranes "on" during all atmospheric flight profile with Orbiter overboard vent.
11.3	Use same fluid interface panels, provide for disconnect separation prior to Tug rotation for deployment. On normal flight, no further Tug-Orbiter fluid interfaces until Tug retrieval & rotation back into payload bay in Tasks 12.9/12.10.	• Provide means to jettison entire Tug/SC in the event of deployment system failure. • Disconnect panels to be capable of being manually disengaged via EVA.
12.10 - 12.12	Use same fluid system Tug-Orbiter interface panels & remate all lines following Tug rotation back into Orbiter cargo bay to enable: • Helium supply for main propellant tank purge bags. • Vent for purge bag • Pressurize and vent main propellant tanks Maintain these interface capabilities during Orbiter entry flight and landing operations.	Provide sensors on interface panels to provide evidence of satisfactory connection to crew. Panels to be capable of being manually reengaged via EVA. Provide capability of purging and repressurizing Tug main propellant lines prior to entry
13.1	Use basic fluid interface panels & lines installed in Task 2.1 or 1.3 to provide capability to support an RTLS abort flight termination. • Provide capability to dump ≈50,000 lb LO_2 and LH_2 within 300 seconds. Provide required pressurization gas for maintaining flight pressure head to expedite propellant dump.	For all return or abort conditions, all interconnecting ducting shall be purged & repressurized with He prior to entry. Rev. A

SYSTEM: FLUIDS		Sheet 5 of 5
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
13.1 (Cont'd)	• Provide LO_2 & LH_2 tank vent capability on completion of dump. • Provide helium for LO_2 & LH_2 purge bags. • Maintain 16 psia in both LO_2 & LH_2 main propellant tanks using vent/pressurization. • Provide helium purge for panels & lines.	Provide sufficient redundancy in vent/purge/pressurization systems to ensure continued performance of these functions after failure of any single component.
13.2	Using basic fluid interface panels & lines installed in Task 2.1 or 1.3 to provide capability to support a pre-deployment abort (results in Orbiter AOA/ATO) flight termination. Provide • Switch from zero-g vent to positive vent for main propellant tanks. • Provide abort pressurization system for both main propellant tanks. • Provide dump lines for both main propellants which exit at aft end of Orbiter and are oriented to provide positive axial thrust. • Control dump flow from initial trickle flow for line chilldown to full flow condition. Terminate dump upon sensing propellant depletion and purge dump lines & panels.	Propellant valves that control dump shall be fail safe. Propellant tank pressurization systems to contain sufficient redundancy to ensure capability of repressurizing tanks after sustaining a failure of any pressurization component.

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SYSTEM: STRUCTURE		Sheet 1 of 4
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
	GROUND OPERATIONS	
5.1	Provide primary structural support of Tug in Orbiter during Tow to Safing Area (SA) or Orbiter Processing Facility (OPF) following landing rollout and to accommodate Tug/SC safing & purging operations. Support must be compatible with Orbiter support locations, interface surface details and loads/strength.	• Tug payload bay support points that transmit Tug/spacecraft loads into Shuttle structure shall be designed with a 25% margin of safety under the most adverse Shuttle design loads, excluding crash landing. • Tug/SC structure shall be grounded to Orbiter structure.
5.1A (RTLS)	Provide same primary support as in 5.1, but capable of supporting added weight of ACPS propellant on-board following Return to Launch Site (RTLS) aborted flight termination.	Same as 5.1, except added weight of ACPS propellant onboard.
5.1A (AOA/ATO)	Provide same primary support as in 5.1, but capable of supporting added weight of ACPS propellant on-board following Abort Once Around (AOA) or Abort to Orbit (ATO) flight termination.	Same as 5.1A (RTLS)
5.2	Continue to provide primary support of Tug/SC (& deployment adapter) as in 5.1. In addition, provide access for installation/removal of cargo bay work platforms & support for same which is compatible with Orbiter clearance requirements. Provide for handling equipment pickup points compatible with Tug-Orbiter support system and Orbiter clearance requirements for horizontal removal (or installation) of Tug & deployment adapter with or without attached spacecraft.	• Same as 5.1 a) Provide Tug attach points to enable life equipment lockup before unlatching Orbiter Tug support. b) Ensure lift equipment interlocked or load limited to preclude Tug liftout while still attached to Orbiter. c) Ensure spring rate deflection difference between empty Tug & Tug/heavy spacecraft do not create clearance problem.
5.3	Continue to provide primary support of Tug/SC (& deployment adapter) as in 5.1 for that part of Task 5.3 accomplished while Tug/SC remains in Orbiter payload bay.	
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SYSTEM: STRUCTURE	Sheet 2 of 4

SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
2.1 (2.1.5-2.1.7)	Provide attach fittings for Tug/Adapter/Spacecraft handling equipment for horizontal load operations which are compatible with Orbiter payload bay support points, interface surface details, loads and clearance requirements. Provide structural mounting for mechanism and fluid/avionics subsystem elements which interface with Orbiter and provide for installation of necessary work platforms to install & verify these subsystem elements.	• Incorporate guides to help position Tug/SC during loading. • Provide personnel, safety rails and bumpers to protect Orbiter. • Same as 5.2(c)
2.2	Continue to provide Tug/Deployment Adapter/Spacecraft, work platform & subsystem interface panel support as in 2.1 during any required extended interface verification tasks.	• Provide hard point mounting & pins for work platforms. • Provide guardrails/belts in dangerous locations.
2.3	Continue to provide primary support & latching for Tug/Deployment Adapter/Spacecraft within Orbiter payload bay as in 2.1. In addition, support devices must be capable of maintaining Tug in proper position within payload bay during Shuttle buildup which will entail Orbiter rotation to vertical attitude and mating to SRM & ET. Support must also be maintained during Shuttle roll out and transport to launch pad aboard mobile launch platform.	• Design support fittings with sufficient safety margins to reduce failure probability to negligible level. • Orbiter/adapter latches should incorporate positive locking devices. Latches to be designed to 25% safety margin under most adverse Shuttle design loads, excluding crash landing.
2.4 & 2.5	Structures functional interface requirements for launch pad installation and verification are covered in Task 1.3.5.	
1.1, 1.2, 1.4 & 1.5	Provide primary support for Tug/Deployment Adapter/Spacecraft within Orbiter payload bay with Orbiter in vertical attitude at launch pad. Support system must be capable of maintaining Tug in proper position during empty status checks, propellant loading, and fully loaded condition of terminal countdown. Support system must be compatible with Orbiter support locations, interface surface details & load/strength capability.	• Provide redundant structural lockup of Orbiter disconnect panels. • Provide positive indication of disconnect panel status.

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SYSTEM: STRUCTURE

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SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
1.3.1 & 1.3.7	Provide primary support as in 1.1, 1.2, 1.4 & 1.5, above.	• Work stands - See 2.2
1.3.2 thru 1.3.6	Continue to provide primary support for Tug/Deployment Adapter/Spacecraft as in 1.1, 1.2, 1.4 & 1.6 above. In addition, provide payload changeout unit pickup/attach points which are compatible with the Orbiter support system & payload bay clearance requirements and permit payload (Tug/Deployment Adapter/Spacecraft) removal & installation at launch pad in vertical using payload changeout device. In addition, provide for access to interface panel locations for connection, disconnect & verification requirements.	• Orbiter/deployment disconnect to have double sequenced locks to prevent disconnect with pressure or toxic fluid in lines. • Provide safety pull pin attachment between Tug & changeout unit. • Design to ensure 3-axis deflections & clearance changes during load transfer from changeout unit to Orbiter will not cause Orbiter-Tug contact. • For interface connections that can't be visually verified, provide positive status indicator devices.
1.3A	Continue to provide primary support as in 1.1, 1.2, 1.4 & 1.6 above during Pad Abort backout procedures including propellant drain operations	
	<u>FLIGHT OPERATIONS</u>	
11.1 & 11.2	Provide primary structural support of Tug/Deployment Adapter/Spacecraft in Orbiter during liftoff and Shuttle ascent flight for fully loaded Tug. Must be compatible with Orbiter support locations, interface surface detail & load/strength, including all flight induced loads (Ref. JSC 07700, Vol. IX, Rev. C).	• Ensure dynamic conditions do not cause Tug/spacecraft & Orbiter interferences.
11.3 & 11.4	Continue to provide primary support as above until start of rotation out of payload bay. During rotation and in fully rotated position provide support through deployment adapter mounting fixture.	• Provide structural capability to jettison entire Tug/SC in the event Tug hangs-up in payload bay. • End effector receptacle to be provided with shield to prevent damage from a missed RMS connection attempt.
11.5, 11.6 & 11.7	Provide support in fully rotated position thru deployment adapter mounting fixture. Provide end effector receptacle(s) compatible with RMS attachment for Tug deployment operations.	

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SYSTEM: STRUCTURE	Sheet 4 of 4

SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
12.4 thru 12.8	Provide end effector receptacles compatible with RMS attachment for Tug retrieval including RMS docking, deployment adapter preparation, maneuver into deployment adapter and adapter latching operations. In addition, provide Tug support thru the deployment adapter mounting fixture during electrical umbilical reconnect and subsequent safing operations. Permit release of RMS after Tug is latched to deployment adapter (Task 12.7).	Same as for 11.1 - 11.7
12.9 thru 12.11	Continue to provide end effector receptacle(s) and support thru the deployment adapter support fittings during rotation back into payload bay. In addition, reinstate remaining primary support and latches once Tug is fully rotated to the stowed position as they were in Tasks 11.1 & 11.2.	Ref. 11.3/11.4, provide ability to jettison Tug/SC if rotation and restowage is not possible. a) Provide manual backup for closing Tug/adapter latches. b) Latches to withstand all flight loads, including crash landing, with any latch failed open. c) Orbiter/adapter to be capable of jettison in event failed adapter prevents closing payload bay doors.
12.12	Provide primary structural support (as in 11.1 & 11.2) for return flight which is capable of supporting all flight induced (re-entry maneuvers) and landing loads.	
13.1 & 13.2	Provide primary structural support for Tug/Deployment Adapter/Spacecraft within Orbiter payload bay during RTLS & predeployment AOA abort maneuvers. Same basic support requirements as in Task 11.1/11.2.	Design to ensure that Tug/deployment adapter/SC deflections will not result in interference with Orbiter.

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SYSTEM: PROCEDURES		Sheet 1 of 9
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
5.1	Provide instructions in MSS/PSS operations checklist to accomplish the following prior to egress: • Verify power & purge gas availability • Set all controls to safe position. Provide instructions in ground crew operations checklist to accomplish the following after ingress: • Verify propellant tank pressure-vent cycling. • Make fluid system vent & purge connections. • Verify all systems status at MSS/PSS station. • Monitor tank purge operations.	• Provide overview safety priority check-list & backout procedures to correct non-safe or incipient failure conditions. • Provide procedures to verify readiness of safety critical Tug/SC systems prior to activation or deactivation. • Pressure lines & vessels to be clearly coded to identify capacity & operating pressure.
5.1A (RTLS)	For an RTLS abort flight termination, provide instructions in MSS/PSS operations checklist to accomplish the following prior to egress: • Verify propellant tank pressure-vent cycling. • Verify availability of power & purge gas. • Set all controls to safe position. Provide instructions in ground crew operations checklist to accomplish the following after rollout and tow to safing area: • Verify propellant tank status. • Position & connect propellant & reactant drain & purge equipment. • Drain ACPS propellant reactants. • Purge tanks as required. • Disconnect drain & purge equipment.	• Provide procedures for assessing safe condition of Tug. Procedures to include requirements for retaining Orbiter in safe area until LH_2 & LO_2 tanks have been purged to safe concentrations. • Provide procedures for ensuring that residual gases in propellant tanks have been purged to safe concentrations before continuing operations.
5.1A (AOA/ATO)	For an AOA/ATO abort flight termination, provide instructions in MSS/PSS operations checklist to accomplish the following prior to egress: • Verify tank condition/status. • Verify availability of power & purge gas.	• Same as 5.1A (RTLS)

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SYSTEM: PROCEDURES	Sheet 2 of 9
SUBSYSTEM:	

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
5.1A (Cont'd.)	• Set all controls to safe position.	
	Provide instructions in ground crew operations checklist to accomplish the following after tow to safing area: • Position & connect ACPS reactant drain & purge equipment. • Drain & purge ACPS reactant tanks. • Connect main tank purge equipment. • Purge main propellant tanks. • Disconnect all drain & purge equipment.	Provide procedures for emergency handling of ACPS propellant spills, including evacuation of personnel, use of SCAPE suits and neutralization of spilled propellant.
5.2	Provide instructions in the ground crew operations checklist to accomplish the following during Tug/SC removal from Orbiter: • Monitor Tug status from MSS/PSS station during preparation for removal. • Attachment of Tug (SC) handling equipment. • Disconnect all Tug/Orbiter and Deployment Adapter/Orbiter interface lines & panels. • Lift Tug (plus D/A & SC) from Orbiter.	Provide ground crew instructions for verifying that all interconnects, latches, etc., are in safe status prior to disconnecting, i.e., no voltage across interface, no residual propellants in lines, no lines under pressure, etc.
5.3	Provide instructions in the ground operations checklist to: • Remove flight data by electrical connection to access stored data. It is assumed Tug flight data will be stored in a mag-bubble or CCD type memory which can be accessed via avionics interface unit & dumped to ground station. No physical data removal nor access is required.	
2.1 & 2.2	Provide instructions in the ground crew operations checklist to assist/accomplish following tasks during Tug installation (horizontal at OPF): • Verify payload bay door open & workstands in place.	Procedures to be sequenced to progressively checkout safety critical items before proceeding to major action steps.

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SYSTEM: PROCEDURE

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SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
2.1 & 2.2 (Cont'd.)	• Verify Tug accommodations in place x Support beam fittings. x Interface panel receptacles. x MSS/PSS panels & interconnect cables. x Lines from P/L bay panels to Orbiter mold line panels • Lift & install Tug/SC into Orbiter • Connect & verify interface lines & panels. x Fluid x Avionics • Verify Tug support/retention latches closed & secure.	• Provide emergency backout or status hold procedures for safety critical steps. • Procedures should include tolerance band warning to alert personnel to potential/incipient safety critical conditions.
2.3	Provide instructions in ground crew operations checklist to monitor Tug/SC status during Shuttle/Orbiter buildup & transport to launch pad. Can be accomplished by Orbiter crew, or provide access for Tug crew to accomplish. Access either to MSS/PSS or to data display in MLP room. Orbiter crew provide access for-or assist connecting Tug rise-off disconnect panels between Orbiter and ground (via MLP).	Provide procedures to verify that all disconnects are safe to connect/disconnect.
1.1	• Provide instructions in ground operations checklist for Orbiter crew to accomplish or assist Tug crew in verifying Tug system status during pad operations & countdown preparation. • Provide LPS software as required for data display at appropriate ground station consoles.	Establish procedural sequence to checkout safety associated equipment before status verification is started.
1.2	Provide instructions in ground operations checklist for Orbiter crew to accomplish/assist Tug crew in Tug propellant loading during final countdown and any required LPS software for: • Purge propellant system • Verify propellant system ready for loading.	Provide clear pad procedures for propellant loading operations, and provide backout procedures for defueling and purging the Tug in the event of launch pad abort (Ref. 1.3A).

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SYSTEM: PROCEDURE		Sheet 4 of 9
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
1.2 (Cont'd.)	• Load LH_2 main tanks. • Load LO_2 main tanks. • Load ACPS propellant.* • Charge helium system. • Top/replenish cryogens as required during final countdown.	*In PCR
1.3	Provide instructions in the Orbiter ground crew operations checklist to provide access for, assist with, or accomplish following tasks for Tug/SC changeout at launch pad. Also, within this task are required actions to routinely install Tug/SC at launch pad. • Provide access, open payload bay doors, provide work platforms. • Safe Tug/SC. • Disconnect all avionic & fluid interface panels. • Attach payload changeout unit and remove Tug/SC. • Install replacement (new) Tug/SC. • Connect avionic & fluid interface panels and verify connections. • Verify all Tug supports/latches positioned and secure. • Initiate purges and return to standby condition.	Ensure the pressure bottles are reduced to standby pressure before Tug removal.
1.3A	Provide instructions in ground crew operations checklist to perform or assist Tug crew in the following tasks associated with launch pad abort: • Safely terminate propellant loading or topping operations. • Return Tug/SC to safe status. • Accomplish propellant drain x LH_2 x LO_2 x ACPS • Purge propellant systems • Vent & safe pressurization system • Secure all systems in safe condition	Establish safe hold position during which satisfactory execution of a completed operation can be verified before proceeding to the next operation. Rev. A

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SUBSYSTEM:	

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
1.4	Provide instructions in the ground crew operations checklist to accomplish or assist in monitoring Tug status during Orbiter final prelaunch operations to secure from payload changeout or pad installation.	
1.5	Provide instructions in the ground crew operations checklist to accomplish or assist with the following tasks during final countdown: • Verify Tug/SC status and ready for launch. • Monitor all Tug/SC systems during final countdown.	• Establish procedures for backout to a safe hold position.
	<u>FLIGHT OPERATIONS</u>	
11.1	Provide instructions in flight crew operations checklists for pilot & MSS/PSS to execute appropriate control and/or override functions based on signals displayed on C&W panels. Functions should include: • Monitor C&W panel. • Verify recording of flight data & relay of flight data to ground control stations.	• Provide emergency procedures that will allow Orbiter crew to override any potentially catastrophic events resulting from Tug/SC equipment failures.
11.2	Provide instructions in MSS/PSS operations checklist to accomplish the following during Tug/SC predeployment checkout: • Transfer control to ground station. • Monitor Tug activation & C/O procedure. • Provide assistance as requested by ground control. • Monitor SC predeployment activation & C/O. • Provide visual monitor via CCTV & report to ground control.	• Provide Orbiter crew emergency procedures/training for safing Tug/SC.
11.3 - 11.8	Provide instructions in MSS/PSS & pilot operations checklist to accomplish the following during Tug/SC rotation, deployment & separation:	• Provide procedures for backup operation to be used if primary deployment system fails. Procedure to include instructions for emergency

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SYSTEM: PROCEDURE	Sheet 6 of 9
SUBSYSTEM:	

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
11.3-11.8 (Cont'd.)	• Activate deployment adapter drive & monitor rotation with CCTV. • Maintain required Orbiter attitude throughout the operation. • Monitor & confirm fully rotated position. • Monitor final Tug/SC activation and verify status to ground station. x Power changeover x Change Tug vent system by closing thru Orbiter vents & open non-thrust H_2 & O_2 vents. • Maneuver & attach RMS to Tug. • Disconnect electrical umbilicals & switch to RF Tug-Orbiter commlink. • Release deployment adapter latches. • Position Tug for final separation & monitor on CCTV. • Release RMS & perform Orbiter separation maneuvers. • Monitor & relay Tug/SC status during initial Tug ACS operations. • Transfer full Tug/SC control to ground station after attaining specified separation distance.	Tug jettison via EVA in event Tug cannot be normally deployed or restowed.
12.1 - 12.9	During Tug/SC retrieval operations, provide instructions in the pilot & MSS/PSS flight operations checklists to accomplish (or assist with) the following: • Upon attaining required Tug-Orbiter retrieval locations, transfer prime control to Orbiter for final rendezvous & docking operations. • Continually relay Tug status to ground stations. • Issue commands to position Tug/SC for rendezvous & docking. • Stabilize Tug position. • Perform TPI & TPF rendezvous maneuvers.	Provide safety critical checklist to verify Tug/SC safe condition prior to retrieval. Procedure to include verification of Tug/SC safety prior to approaching Tug and a final verification of Tug/SC safety just prior to positioning Tug in payload bay. Rev. A

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SUBSYSTEM:

Reference Function Block No.	FUNCTIONAL INTERFACE	SAFFTY/RELIABILITY CRITERIA
12.1-12.9 (Cont'd.)	• Verify Tug systems safe for docking. • Visually inspect Tug /SC in preparation for docking. • Attach RMS to Tug. • Perform final Tug/SC safing operation. • Ready deployment adapter for docking. • Maneuver Tug into deployment adapter. • Make and verify reconnection of avionics interface umbilicals. • Verify closing deployment adapter latches to secure Tug • Safe Tug/SC for stowage in payload bay. Note: Sequence of operations will be controlled by Tug DMS with monitor & override capability in Orbiter. • Deactivate Tug fuel cells. • Retract Tug into Orbiter payload bay and secure. Monitor on CCTV.	Provide procedural sequence to jettison Tug/SC in orbit. Procedure to reflect differences in backout/Tug jettison operations as a function of Tug/Orbiter configuration; i.e., Tug stowed, Tug partially rotated, etc.
12.10-12.12	During preparation for entry flight and landing, provide instructions in MSS/PSS operations checklists to accomplish the following: • Activate purge bag helium flow. • Activate main propellant tank pressurization and maintain (or verify) 16 psia in main propellant tanks. • Monitor & relay status to ground stations. • Verify Tug/SC safe for entry flight. • Monitor C&W panels for Tug/SC status during entry flight, landing & rollout.	• Provide procedures for venting, purging & safing H_2 & O_2 lines between tanks & shut off valves thru engines before locking up lines for entry. • Provide similar procedures for safing fuel cell system. • Provide procedures to reverify hardwire safety control & monitor lines prior to entry.
13.1	During RTLS abort provide instructions in MSS/PSS operations checklists to accomplish the following:	

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SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
13.1 (Cont'd.)	• Configure Tug for and initiate LO_2 and LH_2 dump. • Monitor dump operation & relay status to ground control. • Request ground control assistance as required. • Complete LO_2/LH_2 dump operation and return Tug to safe condition. x Maintain purge bag helium flow. x Maintain tanks at ≈ 16 psia. x Purge panels and lines.	Provide procedures to reinitiate helium pressurization of lines & panels for entry.
13.2	During AOA/ATO aborts initiated prior to Tug deployment, provide instructions in MSS/PSS operations checklists to: • Receive from Mission Control: x Determination of requirement to abort. x Commands to Orbiter & Tug to abort & return Tug to safe status. x Transfer of Tug control from ground station (Mission Control) to Orbiter. • Monitor C&W panels to determine Tug/SC status & relay to ground station. • Accomplish required Orbiter maneuver to settle propellants in preparation for dump. • Initiate tank pressurization and start LO_2 & LH_2 propellant dump. • When propellant dump reaches full flow, terminate OMS or ACS thrusters firing. (Assumes dump action provides adequate thrust for continued propellant orientation.) • Continue to relay Tug status to Mission Control. • Complete propellant dump & return Tug/SC to safe status in preparation for normal entry & landing (See 12.10 - 12.12).	Provide checklist to verify Tug/SC safety prior to entry. Procedure to include provisions for Tug jettison prior to deorbit if Tug indicates unsafe status. Procedure to also include operations associated with safe dumping of main propellants prior to deorbit. Rev. A

SYSTEM: PROCEDURE		Sheet 9 of 9
SUBSYSTEM:		
Reference Function Block No.	FUNCTIONAL INTERFACE	SAFETY/RELIABILITY CRITERIA
13.3	During AOA/ATO aborts initiated after Tug deployment, provide instructions in Orbiter flight crew (pilot & MSS/PSS) operations checklist to: • Receive notification from mission control of requirement to abort Tug (SC) mission. • Establish RF link to Tug. • Monitor mission control action to return Tug/SC to retrieval configuration. • Accept transfer of Tug control from mission control to Orbiter. • Verify Tug status as safe for retrieval & relay status to ground. • Retrieve Tug & stow in payload bay as in Tasks 12.2 - 12.7. • Configure for and monitor Tug status during entry and landing as in Tasks 12.10 - 12.12.	Provide procedures & checklists that determine Tug safety status. Procedures to include alternative operations approaches for both ground and flight crews in the event of a hazardous condition generated by an in-flight malfunction.

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2.4 REFERENCES

The data presented in this section is based upon ground and flight operations and on safety requirements contained in the references listed. In addition, information was extracted from results of a number of prior Tug and Tug-related studies, which are included in the list of reference documents.

1. Baseline Space Tug Ground Operations: Verification, Analysis, and Processing, MSFC 68M00039-4, dated 15 July 1974, Marshall Space Flight Center.
2. Baseline Space Tug Flight Operations, MSFC 68M00039-3, dated 15 July 1974, Marshall Space Flight Center.
3. Tug Operations and Payload Support Study, Vol. 3, Part 1 - Mission & Operations Analysis, SD73-SA-006-3, Contract NAS8-28876 Final Report, dated 5 March 1973.
4. Baseline Space Tug System Requirements & Guidelines, MSFC68 M00039-1, dated July 15, 1974, Marshall Space Flight Center.
5. Space Tug Systems Study (Cryogenic) Final Report, General Dynamics Convair Division report CASD-NAS7-3033, dated January 1974.

2.5 BIBLIOGRAPHY

Baseline Space Tug Configuration Definition, MSFC 68M00039-2, dated 15 July 1974, Marshall Space Flight Center.

Space Shuttle System Payload Accommodations, JSC 07700, Volume XIV (Revision C), dated 3 July 1974, Johnson Space Center.

Shuttle System Ground Operations Plan, K-SM-09, dated 18 December 1973, Kennedy Space Center.

Launch Site Accommodations Handbook for Shuttle Payload (Draft Copy), dated 1 February 1974, Kennedy Space Center.

Safety Policy and Requirements for Payloads Using the National Space Transportation System, Revised February 1975, NASA Hdqtrs.

SECTION 3

PAYLOAD FUNCTIONAL INTERFACE REQUIREMENTS DEFINITION AND SERVICES ACCOMMODATIONS TRADE

Because Tug payloads compete with the Tug for Orbiter-supplied services such as power and data processing, an early study task during Task 2 was analysis and identification of the accommodations/support services required by Tug payloads and the determination of their safety requirements. This effort started with an analysis of the requirements of all Tug payloads as specified in current reports by NASA and Department of Defense (DOD). Primary source of NASA/commercial spacecraft interface requirements with Space Tug was the NASA Payload Descriptions document for Automated Payloads. Analysis of available data on DOD payloads identified few unique requirements. Data from the Space Shuttle Payload Descriptions (SSPD) was therefore used for this task since it encompassed most of the requirements of all Tug payloads.

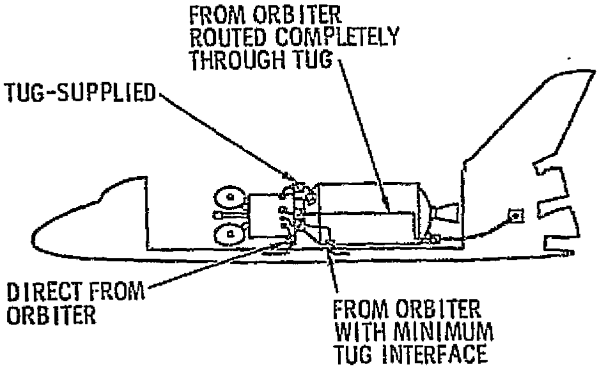


Figure 3-1. Payload Services Accommodating Choices

In addition to the SSPD data used to establish levels of support, two other sources were used to obtain detailed interface data. Interface requirements based on composite spacecraft needs were obtained from the McDonnell Douglas (MDAC) Payload Utilization for Tug (PUT) study and the exchange of preliminary data from their interim upper stage (IUS)/Tug Payload Requirements Compatibility study. Specific interface requirements obtained from Viking were used as a typical complex spacecraft requirements for comparison purposes with the PUT data.

Once the service requirements were defined, analyses were made to determine the best method of accommodating these services. Figure 3-1 shows the four possible implementation techniques. Important considerations used during this evaluation were:

Who does it?	Is the service satisfied by the Tug or the Orbiter? If the Orbiter potentially provides the service, the Tug must be considered primarily for its service transmission acceptability.

How is it transmitted?	Do all functions have to be individually routed, or may some be combined? — i.e., data interleaved and multiplexed, fluids use common ducting.
Where are services routed?	Should they go completely through the Tug, partially through Tug, or direct from payload to Orbiter?

The approach used and resolution of these three questions is contained in Sections 3.1 through 3.4, which discuss the development of payload service requirements, fluid services accommodations trade, avionics services accommodations trade, and the payload trade study summary, respectively.

The Payload/Orbiter Services Accommodations trade study was accomplished early in the study, so that results could be fed into Task 2 subsystems analyses along with Tug functional requirements identified in Task 1.

The combined Tug and payload requirements were used in Task 2 to assess the impact on Orbiter equipment allocation, service panel and raceway space requirements, MSS/PSS panel requirements, power and RF transmission requirements, and crew tasks requirements/allocation. The initial services accommodation trade results were also provided to MDAC for use in the Tug Payload Requirements study then in progress. Data generated by MDAC contributed in turn to update results of the payload/Orbiter services accommodation trade.

The initial and complete documentation of the Interface Study services trade is contained as Appendix A in this final report volume. This section summarizes and updates the methodology employed, conclusions reached, and service implementation recommendations.

3.1 PAYLOAD INTERFACE REQUIREMENTS

The first step in the Payload Accommodations trade was to determine what Tug payload requirements were. To obtain this information, an analysis of the requirements of all Tug payloads as specified in current reports by NASA and DOD was performed. Data from the current MSFC/GDC study, Space Shuttle Payload Descriptions (SSPD), was used since it encompassed most of the requirements of all Tug payloads.

The level of support demanded by the payloads was compared with the level of support provided by Orbiter and Tug as given in JSC 07700, Vol. XIV, for Orbiter, and in MSFC 68M 00039 for Tug. Trade studies were performed to define a reasonable support service level for Tug payload use.

The payload services investigated during this study included only those needed when Tug plus payload were attached or in close proximity to the Shuttle Orbiter. Service requirements during other mission phases were addressed by the appropriate parallel MSFC sponsored study. (See Volume I, Section 3.)

Table 3-1. Payload Interface Requirements Source Documents

TUG REQUIREMENTS	DOD SPACECRAFT	NASA/NON-NASA SPACECRAFT
1. BASELINE SPACE TUG SYSTEM REQUIREMENTS & GUIDELINES (MSFC68M00039-1) 2. BASELINE SPACE TUG FLIGHT OPERATIONS (MSFC68M00039-3)	3. DOD MISSION MODEL FOR STS (REV 3) 4. PAYLOAD INTERFACE STUDY (MDC G 4801) 5. INTERIM UPPER STAGE SYSTEM REQUIREMENTS 6. AFSCF SPACE/GRD INTERFACE (TOR-005 (6110-OD)-3, REF 1) 7. PAYLOAD-SHUTTLE INTERFACE DATA BOOK (MSFC-PD-73-1)	8. SUMMARIZED NASA PAYLOADS DESCRIPTIONS, AUTOMATED P/L LEVELS A&B DATA (SSPD DATA) 9. A STUDY OF PAYLOAD UTILIZATION OF TUG (MDC G 5356) 7. PAYLOAD-SHUTTLE INTERFACE DATA BOOK (MSFC-PD-73-1)

3.1.1 REQUIREMENTS SOURCE DATA. Payload data sources used to define Tug payload service requirements are shown in Table 3-1. A variety of sources providing data on Tug requirements, DOD spacecraft, and NASA/Commercial spacecraft were utilized.

Primary source of NASA/Commercial spacecraft interface requirements with Space Tug was the NASA Payload Descriptions document for Automated Payloads. These requirements are defined to two levels. Level A is a summary of the NASA payload descriptions for all automated payloads to be flown with the Shuttle only and Shuttle plus Space Tug/IUS. Detailed definitions of automated payloads are contained in Level B Data Book. Payloads to be launched during the IUS operational period from 1980 through 1984 are contained in the Level B Data Book in more detail than Tug payloads, which are in an earlier conceptual phase. Level B data, in many cases preliminary or incomplete, is available for 28 of the 50 IUS/Tug payloads identified.

Primary source of DOD spacecraft interface requirements was the DOD Space Transportation System Payload Interface study performed by MDAC. In this study the contractor analyzed in depth three existing DOD satellites: Defense Satellite Communication System II (DSCS II), Defense Support Programs (DSP), and Fleet Satellite Communication (FLTSAT-COM). These satellites are similar to the majority of the satellites that will be advanced into the Shuttle era. The objective of this study was to define the interface concepts required to achieve compatibility with Shuttle and Tug vehicles.

Available data on DOD payloads does not include detailed descriptive information similar to that in the Level A or B NASA payload data due to the classified nature of DOD payloads. A total of 17 payloads was identified for post-1984 missions. From a review of the documents available, few requirements unique to DOD payloads were identified. As a result, payloads listed in the July 1974 "Summarized NASA Payload

Descriptions," Levels A and B, are assumed to be representative of DOL payloads and were used as guidelines for the payload interface study.

Specific service needs and levels of support were developed for each potential Tug/Orbiter interface. Fluid service requirements were generally straightforward: Quantity two 0.5 inch (1.27 cm) water lines, one 1.5 inch (3.81 cm) propellant vent line, etc. Electrical service levels were more difficult to standardize due to the large variation of payload desires for any one electrical service.

The electrical power summary data chart (Figure 3-2) is a typical reproduction of applicable data from the Space Shuttle Payload Description Activity for Automated Spacecraft, Level A document. Generally, Level A data includes both Tug spacecraft and those flown without Tug for all mission phases. The data evaluated has been limited to payload requirements only for those mission phases while Shuttle attached. Tug spacecraft are identified by a bullet following the payload number.

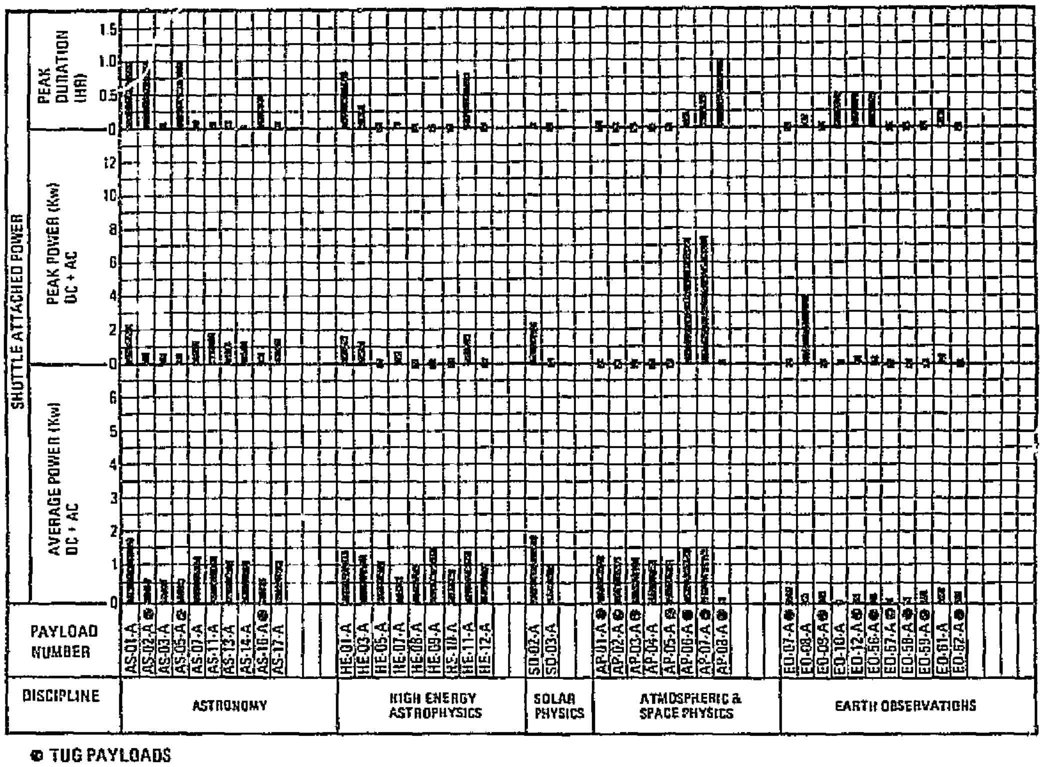
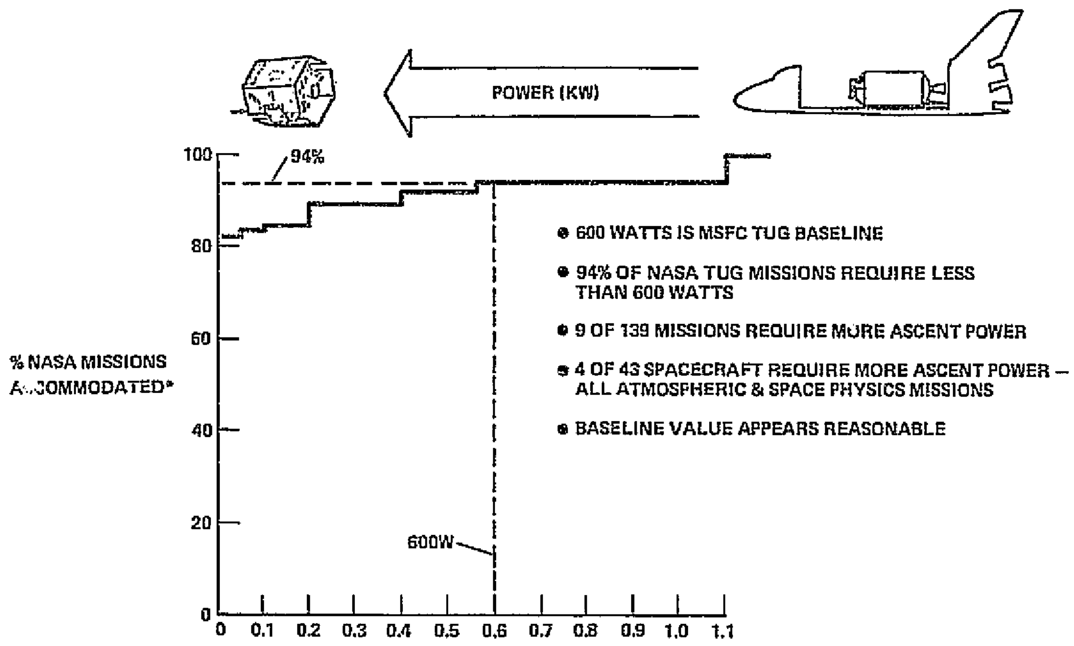


Figure 3-2. Typical SSPD Data (Electrical Power)

Figure 3-3 illustrates the approach used to evaluate the baseline values established for payload support requirements. The number of SSPD Tug payloads and missions accommodated by a given Tug or Orbiter capability was determined. Figure 3-3 displays the sensitivity of accommodated missions to a change in capability. In this example, a 600 watt capability accommodates 94% of the missions reviewed. To



*FROM MSFC'S PRELIMINARY "SUMMARIZED NASA PAYLOAD DESCRIPTIONS – AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

Figure 3-3. Power Required by Payload During Ascent

capture the final 6% the capability would have to be nearly doubled. Similar evaluations were performed for 12 parameters in the avionics area: power, data transfer and data management. Details of these trades are included in Appendix A.

3.1.2 FLUIDS REQUIREMENTS SUMMARY. Based on a compilation of payload requirements from the various sources available, a tabulation was made of payload interface service needs for each payload requirement identified in the general categories of liquids and gases.

Table 3-2 indicates the types of fluid services needed. Because the interface requirements (line diameter flow rates, operational time period, etc.) of these services were very dependent on the service implementation method (line routing), the level of service description was determined during the accommodations trade.

3.1.3 AVIONICS REQUIREMENTS SUMMARY. Table 3-3 lists the general composite avionic interface service requirements obtained from SSPDA data.

Table 3-2. Payload Fluid Service Requirements

PAYLOAD REQUIREMENTS (FROM SSPD DATA)		INTERFACE SERVICES REQUIRED
LIQUIDS:	PROPELLANTS (N_2H_4, MMH, N_2O_4, CESIUM)	FILL, DRAIN, VENT, DUMP
	COOLANTS (H_2O, FREON)	CIRCULATE TO HEAT SINK
	CRYOGEN (LHe)	FILL, DRAIN, VENT, DUMP
GASES:	PRESSURANTS (GHe, GN_2)	FILL, VENT,
	BATTERY	VENT
	SHROUDS	MAINTAIN PURGE PRESSURE

Table 3-3. Payload Electrical Service Requirements

Payload Requirements (From SSPD Data)		Interface Services Required
Data:	Communication	Transmit, Receive, Store
	Status & Control	Condition, Override, Confirmation
	Caution & Warning	Condition, Control
Electrical Power		Transmit/Supply

As described in Section 3.1.1, the evaluation of the SSPD data resulted in recommended baseline values for the level of support from Orbiter or Tug. Table 3-4 lists the worst case support required by any payload, Interface Study recommended level of support, and the percent of payloads accommodated by that level of support for each of the support functions.

Since some payload requirements (or desired values) were not met by the support levels recommended, these payloads were identified.

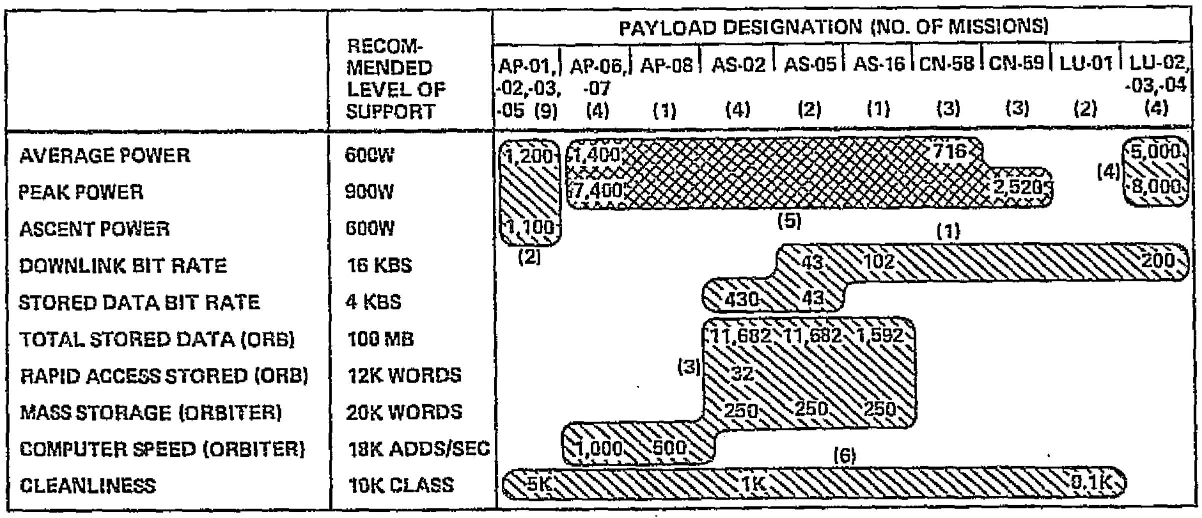
The payloads that require more support than the recommended levels are shown in Table 3-5 along with their requirements. The net accommodation is 78% when all levels of support are imposed simultaneously. As noted, only average and peak power requirements impact the Tug design, which can accommodate 92% of the payloads studied.

The Orbiter percentage was obtained directly from the 12 baseline parameters with the exception of rapid access storage capability, which was increased from 10 to 12K words. The greater Tug accommodation percentage was obtained by not precluding transmittal of Orbiter to payload services, even though payload demands exceed planned Orbiter capabilities. The resulting requirements (shown in Table 3-4) for these 12 areas are briefly discussed here:

Table 3-4. Recommended Avionics Support for Tug Payloads

Support Function	Maximum Level of Support as Given in SSPD Data	Recommended Level of Support From Orbiter/Tug	Payloads Accommodated (%)
Average Power	5,000W	600W	85
Peak Power	8,000W	900W	86
Ascent Power	1,100W	600W	94
Uplink Rate	2 Kgs	2 Kbs	100
Downlink Rate	430 Kbs	16 Kbs	92
Stored Data Rate	430 Kbs	4 Kbs	96
Total Stored Data	11,682 Mb	100 Mb	95
Computer Word	32 bits	32 bits	100
Rapid Access Storage	32K words	12K words	94
Mass Storage	250K words	20K words	94
Computer Speed	1,000K adds/sec	18K adds/sec	96
Cleanliness	Class 100	Class 10,000	96

Table 3-5. Payload Requirements not Accommodated



ORBITER LIMITATIONS

(1) CAN BE ACCOMMODATED WITH PROPOSED TUG INTERFACES

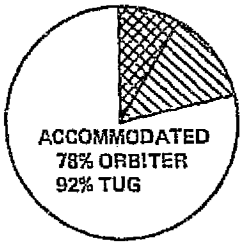
(2) CAN BE ACCOMMODATED WITH PROPOSED TUG INTERFACES (<600W THROUGH TUG)

(3) INDEPENDENT OF TUG INTERFACES

(4) REQUIREMENTS APPEAR SUSPECT

(5) ORBITER/TUG LIMITATION; PROVIDE MISSION KIT

(6) SHUTTLE GSE LIMITATION; PROVIDE MISSION KIT



a. Average Power — The MSFC baseline Tug documentation allocated 600 watts of Tug supplied power for delivery to Tug/spacecraft after deployment from the Orbiter. The results show that a 600 watt accommodation satisfies 85% of the spacecraft for Tug missions; 11 OF 43 PAYLOADS EXCEED THIS VALUE and 21 OF 139 MISSIONS EXCEED THIS VALUE. Some information concerning the split between spacecraft and monitor and control power is contained in the level B SSPDA data for a limited number of the 43 payloads. For those identified, more power is generally required for the control equipment than for the spacecraft vehicle.

b. Peak Power — Peak power requirements are not specifically included in the Tug baseline data. Typically, however, peak power is assumed to be 1.5 times the average power. The 900 watt reference shown results in a similar percentage of acceptable payload accommodations, with generally the same group of spacecraft as in on-orbit average power exceeding the reference capability. That is: 86% OF NASA TUG/ORBITER MISSIONS REQUIRE 900 WATTS OR LESS, 20 OF 139 MISSIONS EXCEED THIS VALUE, AND 10 OF 43 PAYLOADS EXCEED THIS VALUE.

c. Ascent Phase — During ascent, the payload plus its Orbiter-mounted and control equipment generally requires less power than during on orbit pre-deployment operations. This enables the 600 watt baseline Tug reference capability to satisfy 94% of the missions. Since 1100 watts (almost double the reference value) is needed to pick up the four remaining payloads, the 600 watt power requirement appears reasonable.

d. Total Energy — Total Orbiter energy available for total payload use (Tug, Tug deployment adapter, Tug monitor and control equipment, spacecraft, and spacecraft monitor and control equipment) is 50 kilowatt hours. Estimates of the energy needs of Tug and its peripheral equipment indicate the 50 kwh available should satisfy at least 90% of the Tug/spacecraft missions, and that the baseline appears adequate.

e. Uplink Rate — The Orbiter uplink capability of receiving and relaying 2048 bits per second to spacecraft satisfies 100% of the identified payload requirements and is therefore adequate.

f. Downlink Rate — The Orbiter baseline provides for transmission of 16 thousand bits per second of spacecraft to ground data. Ninety-two percent of the mission model is satisfied by this capability; therefore, the Orbiter baseline appears to be reasonable. SIX OF 43 PAYLOADS REQUIRE HIGHER BIT RATES AND 11 OF 139 MISSIONS REQUIRE HIGHER BIT RATES.

g. Stored Data Rate — Although no specific Tug or Orbiter provisions have been identified for storage of spacecraft data, data storage would probably be accomodated by the Orbiter for spacecraft-attached mission modes. As indicated by

Table 3-4, a four-thousand bit per second data stream for storage purposes would satisfy 96% of the identified spacecraft requirements. Since an order of magnitude increase would be necessary to include the six excluded missions, the 4 kbps storage data bit rate should be acceptable.

h. Total Data Storage Capability — As previously stated, storage capacity for Shuttle-attached spacecraft is assumed to be an Orbiter-supplied accommodation. A capability to store 100 megabits of data would satisfy 95% of the spacecraft requirements currently identified. One hundred percent accommodation requires a storage capacity two orders of magnitude greater. One hundred megabits appears to be a realistic baseline accommodation.

i. Computer Word Size — The 32 bit computer word length provided by the Orbiter accommodates 100% of the NASA Tug payloads.

j. Rapid Access Memory — Rapid access memory requirements for SSPDA payloads have been analyzed to show the percentage of total mission payloads that can be accommodated by a given memory size. The Orbiter baseline is currently sized for 10K words. It is recommended that this be increased to 12K words because there are 15 payloads (EO-09, EO-59, and EO-62) that require 12K words, which if included in the Orbiter capability increase mission accomplishment from 83% to 94%.

k. Mass Storage — Mass storage requirements for SSPDA payloads have been compiled to show the percentage of payloads that can be accommodated with a given Orbiter bulk memory. The Orbiter baseline currently identified 20K words allocated for payload use, which will accommodate 94% of the payloads. Seven payloads (AS-02, AS-05, and AS-16) require 250K words. A baseline capability of 20K words appears to be reasonable.

l. Computer Speed — Computational speed requirements for SSPDA payloads have been identified. The chart shows the percentage of total mission payloads that can be accommodated by a given level of computational speed. The Orbiter baseline of 18,000 computations/second will accommodate 96% of the payloads. Payloads AP-06 and AP-07 require 1,000,000 computations/second and payload AP-08 requires 500,000 computations/second. There are five total missions with these high computer speed requirements. The Orbiter capability of 18K appears to be reasonable for the Tug payloads, although that is the total Orbiter capability to satisfy both Tug and Payload requirements.

Specific requirements of SSPD payloads that cannot be attained with the recommended levels of Orbiter/Tug support are identified in Table 3-5. SSPD payload designations are shown across the top of the Table and recommended support levels that should be Orbiter/Tug provided are shown in the left hand column. The level of support desired by the payload is shown in the table. In most cases a single payload is deficient in more than one parameter. The footnotes show that most of the deficiencies are either due to limitations in the basic capability of the Orbiter, or to payload requirements that appear to be suspect.

Spacecraft requirements associated with downlink and stored data bit rates can easily be satisfied by Tug since these are Orbiter services which only require Tug transmission.

Four service categories, total data stored, rapid access storage, mass storage, and computer speed are assumed to be Orbiter-peculiar services provided to payloads while in the attached mode, which have no effect on Tug interface requirements.

Some average and ascent power requirements are assumed to lie within the 600 watt baseline Tug capability since Level B SSPD data indicates that over 50% of this power is required by Orbiter-mounted monitor and control equipment rather than the spacecraft vehicle.

The remaining deficiencies were used to obtain the 92% Tug accommodation listed. If Orbiter capability is increased to satisfy these requirements, accommodation should probably be achieved by direct spacecraft-to-Orbiter mission peculiar kits.

These recommended service levels were used to evaluate umbilical services routing trades (Section 3.3) and to develop the resulting accommodations definition. Subsequent changes in some service levels resulted from the parallel Tug Payload Requirements Compatibility study performed by McDonnell Douglas Corporation under Contract NAS8-31013. The summary (Section 3.4) includes this updated data.

3.1.4 SAFETY REQUIREMENTS. Tug payload safety requirements were obtained and documented in a similar manner as for Tug safety requirements (Section 2.2).

The NASA Tug requirements document (MSFC 68M00039-1) was reviewed to identify the payload safety requirements that are applicable to the Interface study. Except for the addition of reference to hazards to the public and the ecology, the principal safety requirement remains essentially unchanged from those used in previous Tug-related studies. That is, "No single Tug payload failure shall result in a hazard that jeopardizes the flight or ground crews of the Shuttle, general public, public/private property, and the ecology." It is, of course, of paramount importance that this particular criterion be complied with. In any instance where compliance with this criterion cannot be achieved, the non-compliance and the rationale for non-compliance, must be identified.

Additional safety requirements that are deemed to be specifically applicable to the Interface study have been extracted from the requirements document and included in Table 3-6. The "Reference Paragraph" column in this table provides a cross reference between the table and MSFC 68M00039-1. Where two or more criteria are grouped into a single requirement, this grouping is so noted by the addition of a paragraph reference(s) in parenthesis. The safety requirements have been further categorized in the following manner:

R - Indicates a safety requirement that must be specifically addressed during the study. We must either show how the requirement is reflected in our recommended interface designs or show specific rationale for any non-compliance.

D - Indicates a safety requirement that can only be satisfied during detail design. The designs developed during the study should, however, contain no feature that would preclude attainment of the requirement during detail design.

I - Indicates a joint safety requirement between the interface subsystems and other Tug/Orbiter/payload systems. We must show how our designs are consistent with the related Tug/Orbiter/payload safety requirements.

Table 3-6. Tug/Payload Safety Requirements

	Tug/Spacecraft Requirements	Reference Paragraph	Category
1.	Spacecraft shall provide caution and warning data to the Orbiter and crew for safety critical functions while aboard or in the near vicinity of the Orbiter.	3.2.6.2.3 a (2)	I
2.	Provisions shall be made to confirm that all safety critical Spacecraft/Tug and Spacecraft/Orbiter interfaces are securely connected.	a (9)	I
3.	Any Spacecraft subsystem operation which impacts safety during the launch and entry phases shall be monitored via C&W (caution and warning) and controlled from the Orbiter flight station.	3.2.6.2.3 a (12)	I
4.	A means shall be provided for controlling the venting of Spacecraft fluids while in the Orbiter payload bay.	a (15)	I
5.	Provisions shall be made for verifying critical Spacecraft systems readiness before activation.	a (16)	I
6.	All electrical, mechanical and fluid connections between the Spacecraft and Tug and/or Orbiter shall be designed to be fail safe.	a (17)	I
7.	Systems containing fluids that are subject to decomposition through contamination or loss of passivation (such as monopropellants) shall be safed by appropriately sized and located vents for the worst case decomposition rate.	a (23)	I
8.	A redundant relief capability shall be provided for Spacecraft tanks which automatically limits the maximum pressure. Relief shall be through the Orbiter vent system overboard. Overpressure relief capacity shall be redundant to vent capacity. (When vent capability is provided, relief capability need not be redundant.)	b (2)	I
9.	Spacecraft propellant drain, and vent interface with the Orbiter shall permit Spacecraft main propulsion system propellant venting, and emergency detanking (whether Orbiter is in horizontal or vertical attitude) until launch commit, with the Orbiter payload bay doors closed or open.	b (4)	I

Table 3-6. Tug/Payload Safety Requirements (Contd)

	Tug/Spacecraft Requirements	Reference Paragraph	Category
10.	Spacecraft fluid fill, drain, and vent umbilical disconnects shall have positive sealing at disconnect, whether the action is intentional or accidental. Provisions shall be made to prevent pressure buildup in the system. Dual valving shall be provided to ensure emergency drain if one valve should fail.	b (6)	I
11.	Spacecraft cryogen tank thermal protection systems shall be designed to minimize (below ignition regimes) accumulation of flammable fluids resulting from propellant system leakage.	b (17)	I
12.	Propulsion system safety critical data, start sequence logic status and valve positions shall be monitored and signals provided to the Orbiter for corrective action to be taken.	3.2.6.2.3 c (1)	I
13.	Provisions shall be made to verify completion of main engine propulsion system safing prior to retrieval.	c (8)	I
14.	Message signals from Spacecraft systems shall be provided at the Shuttle Data Management System Interface. Measurements shall include at least Spacecraft latched/released indication, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, velve positions, temperature and pressure measurements, and failure indications.	d (1)	I
15.	Spacecraft critical command and control circuitry shall be designed to be fail-operational/fail safe as a minimum.	d (3)	I
16.	Automatic event sequencing programs and automatic controls whose actuation could affect flight personnel safety shall be operative only by the Orbiter, or by ground control enabling switches (command over-ride), e.g., pyrotechnic sequences, automatic deployment sequences, etc.	d (4)	I
17.	Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification.	d (6)	I
18.	Spacecraft propulsion system start sequence logic status, and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management System Interface. The transmission shall be through Tug hardware while within the payload bay but once outside it may be transmitted either directly from the Spacecraft or via the Tug telemetry system.	d (7)	I
19.	Spacecraft shall have a means of shutting off their electrical power under emergency conditions.	e (4)	I
20.	Safety critical control circuits shall be capable of being verified.	e (14)	I

Table 3-6. Tug/Payload Safety Requirements (Contd)

	Tug/Spacecraft Requirements	Reference Paragraph	Category
21.	Provisions shall be included for Spacecraft caution and warning functions which will provide both audible and visual warning to Orbiter crew of hazardous situations while the Spacecraft is aboard the Orbiter or being deployed.	e (16)	I
22.	Fuel cells are to be activated only after TBD distance from the Orbiter.	e (18)	I
23.	Means shall be provided to control toxic, flammable, explosive and corrosive substances aboard Spacecraft and to preclude their accumulation in or venting into the Orbiter payload bay. The maximum operating temperature shall be taken into consideration as a generative source of hazardous fluids.	h (1)	I
24.	Integrated checkout and testing of safety critical Spacecraft systems shall be conducted prior to installation on the Tug and verified after installation into the Orbiter.	3.2.6.2.4 d	I
25.	Spacecraft shall have capability for the Orbiter crew to dump hazardous fluids and vent pressurants overboard within TBD seconds in an abort situation.	i	I
26.	Electrical umbilical disconnects between the Orbiter and the Spacecraft and/or Tug shall not have power applied during disconnect.	j	I

3.2 FLUID SERVICES ACCOMMODATIONS TRADE

This interface service routing implementation trade study used the approach depicted in Figure 3-4 to describe fluid service requirements.

To determine the answer for "Where do services go?" an understanding of Orbiter umbilical panel and routing provisions is needed.

Based on data from JSC 07700, Space Shuttle System Payload Accommodations, Vol. XIV, Rev. C, interface panel locations for Tug and payloads are as shown in Figure 3-5.

The primary panel for direct payload interfaces, which is terminated at T-4 hours, is located on the Orbiter left side at Station 835. Both fluid and electrical services are available at this location. Subsequent to T-4 hours, the panel is covered by a door that remains closed during flight. An inflight disconnect within the payload bay will be required between the Tug/payload and service lines routed to it from T-4 panel.

Internal to the cargo bay is a payload electrical service panel on the right sidewall at Station 695. This panel is primarily for direct connection to the Orbiter fuel cell power supply.

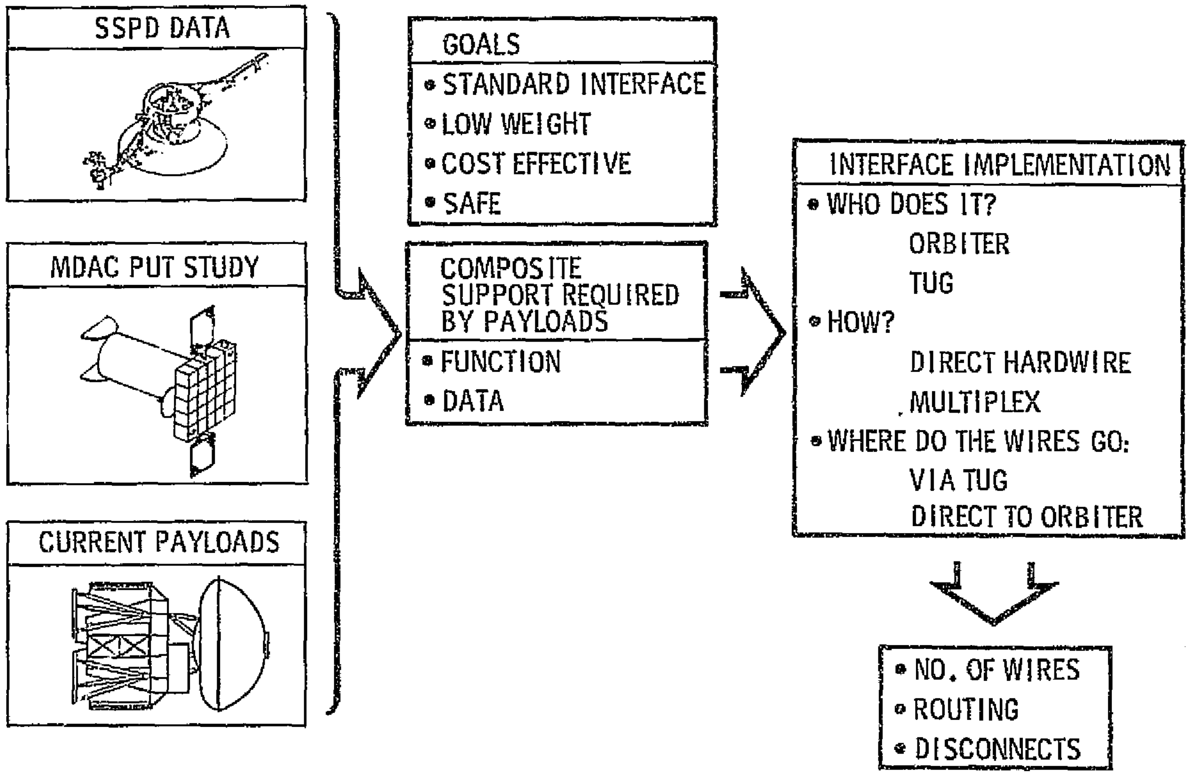


Figure 3-4. Fluid Services Implementation Approach

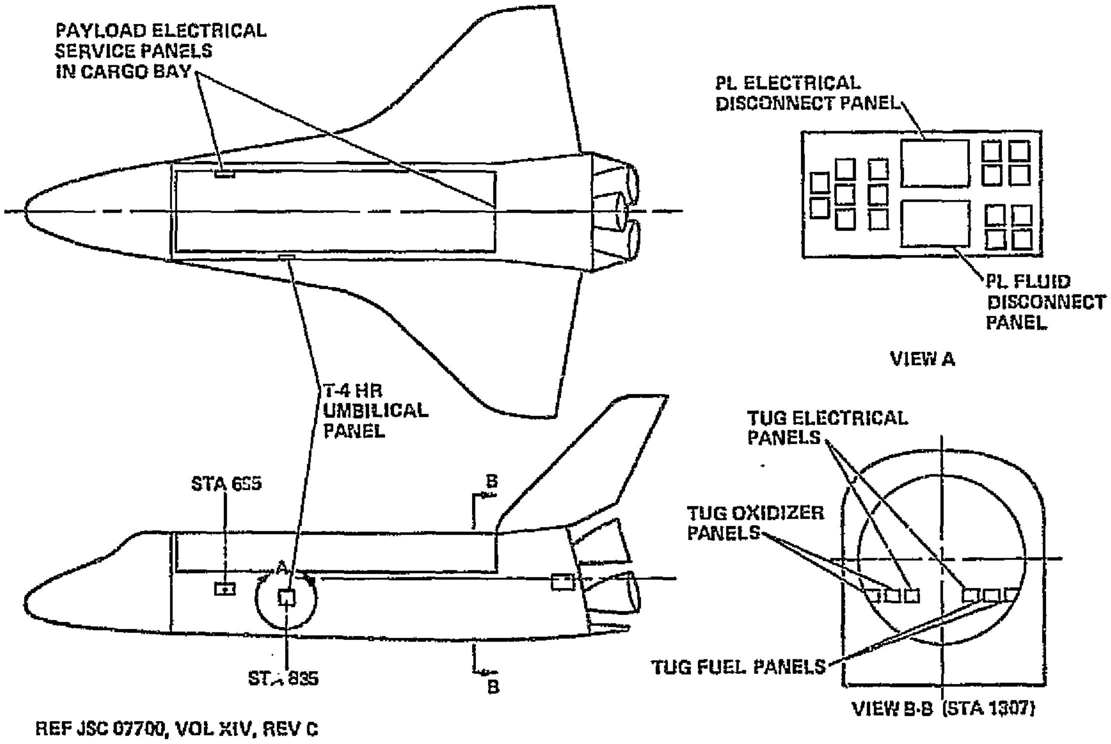


Figure 3-5. Tug and Payload/Orbiter Interface Panel Locations

Aft panels are located at Station 1307 on the cargo bay aft bulkhead. Included are Tug fuel, oxidizer, and electrical panels on the lower half of the bulkhead and OMS/storable propellant fluid and electrical panels near the top of the bulkhead.

RTG coolant interfaces are located at Station 1307 for ground cooling and near the cargo bay forward bulkhead for inflight cooling.

3.2.1 REQUIREMENTS EVALUATION/SCREENING. Ten payload fluid accommodations were assessed to determine the best operational and physical technique for satisfying the interface. Details of these investigations are contained in Appendix A of this volume. Three of the more interesting evaluations are contained in this subsection as examples.

GROUND RULES:
- ONE HOUR FOR FILL OR DRAIN
- MULTISTAGE TANKS ARE MANIFOLDED WITHIN PAYLOAD
- PAYLOADS INSTALLED IN VERTICAL POSITION AT PAD
- MONOPROPELLANT REQUIRES 1 LINE, BIPROPELLANT 2 LINES

OPTIONS:

FILL/DRAIN MODE	LINE DIA IN. (cm)	INST WT LB/LINE (kg/LINE)	ADDED INTERFACES ACTIVE GROUND	ADDED INTERFACES ACTIVE FLIGHT	ADDED INTERFACES PASSIVE GROUND	ADDED INTERFACES PASSIVE FLIGHT
1. VIA T-4 PANEL DIRECT TO PAYLOAD	0.375 (0.95)	6 (2.7)	1	2		
2. THRU TUG VIA AFT UMBILICALS	0.5 (1.27)	21 (9.5)	1	3		1
3. IN PAYLOAD CHANGEOUT ROOM	≤0.375 (≤0.95)	2 (0.9)			1	

RECOMMENDATION: FILL & DRAIN IN PAYLOAD CHANGEOUT ROOM
- MINIMUM WEIGHT & COMPLEXITY
- NO ACTIVE INFLIGHT DISCONNECTS
- NO STORABILITY OR SAFETY PROBLEMS IDENTIFIED
- NO TUG OR ORBITER INTERFACES

Figure 3-6. Payload Propellant Fill and Drain

3.2.1.1 Propellant Fill and Drain. Liquid propellant fill and drain can be accomplished in any of the three modes shown in Figure 3-6, with payloads assumed to be vertical and one hour available for fill. Payloads with multiple stages are assumed to manifold fill/drain lines within the payload adapter or payload to minimize number of interfaces with the Tug or Orbiter.

Of the three modes identified, fill and drain of propellants in the Payload Changeout Room (PCR) is the recommended method. Evaluation of safety aspects indicate that the storable propellants identified are stable in nature and will not create a safety problem due to loading ahead of installation into the Orbiter. Experience to date with satellites and manned vehicles has shown no instances where propellant reactions occurred subsequent to propellant loading that would have resulted in a hazard under equivalent conditions for Tug/Orbiter payloads.

Loading of propellants in the PCR results in minimum payload/Tug weight and complexity with only a single manual disconnect required for each propellant source. Manifolding on multistage payloads is also avoided.

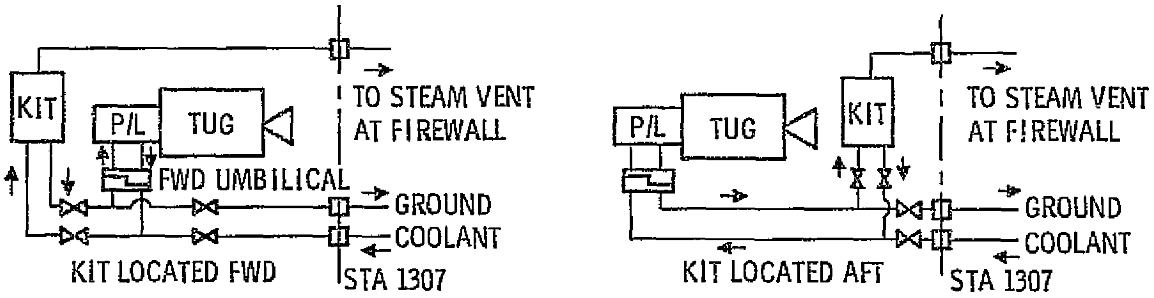
Propellant fill/drain via the Orbiter requires the addition of two to three inflight disconnects, T-0 or T-4 hour umbilical disconnects, and associated plumbing for each fluid.

Line diameter, estimated installation weight, and number of added interfaces, both active and passive, for each fill/drain mode are indicated.

3.2.1.2 Payload Cooling (RTG). Eleven NASA planetary payloads and one DOD payload contain radioisotope thermoelectric generators (RTG) that require cooling prior to launch and in flight prior to Tug deployment. Coordination with Rockwell/Space Division indicated that baseline RTG cooling provisions are as outlined under the Requirements and Ground Rules/Assumptions following:

a. Requirement — Reject up to 50,000 Btu/hr (14,640 watt)
    1. Prior to launch — ground source.
    2. During boost.
    3. On orbit prior to Tug deployment.
    4. During entry and flyback for aborts.
b. Ground Rules/Assumptions
    1. Demineralized, deionized water supplied for ground cooling.
        a) Required until T-0.
        b) Interface at Station 1307.
    2. Use water boiler on orbit, size supply for three orbits plus entry/flyback plus 30 minutes post landing.
    3. Use water supply heat capacity for boost cooling.
    4. Orbiter ATCS not available for RTG cooling (<21,000 Btu/hr (6150 watts) available for Tug plus payload requirements).

To absorb the 50,000 Btu/hr (14,640 watt) RTG cooling load, a separate RTG coolant kit is required since the Orbiter ATCS is capable of absorbing only 21,000 Btu/hr (6150 watts) from the combined Tug and payload. The kit consists of a water boiler, a steam vent line approximately three inches (7.6 cm) in diameter, pumps, isolation valving, approximately 325 pounds (147 kg) of water and distribution lines between the payload, airborne cooling kit, and ground prelaunch water supply. Total kit weight is approximately 900 pounds (408 kg).



RTG WATER BOILER KIT INSTALLATION OPTIONS

INTERFACE ASSESSMENT

- ADEQUATE SPACE EXISTS EITHER FWD OR AFT FOR KIT INSTL
- NO APPRECIABLE ORBITER CG IMPACT WITH BASELINE TUG (CG MOVES APPROX 8 IN. (20 cm) AFT, WELL WITHIN ALLOWABLE ENVELOPE)
- FWD VS AFT LOCATION HAS NO EFFECT ON TUG OR PAYLOAD
- SUPPORTS REQUIRED FOR KIT
- AFT LOCATION MINIMIZES STEAM VENT LINE LENGTH, WEIGHT & INTERFACE IMPACT

RECOMMENDATION

- LOCATE KIT AT AFT END OF CARGO BAY - 12 PAYLOADS. MOUNT ON D/A
- USE LINES FROM KIT TO PAYLOAD FOR BOTH GROUND & AIRBORNE COOLANT FLOW (PROVIDE ISOLATION VALVING)
- VENT WATER BOILER STEAM AFT THROUGH NOZZLE ON ORBITER FIREWALL

Figure 3-7. Payload RTG Cooling Concepts

The airborne water supply is sized to provide cooling for three orbits, during entry and flyback, and for 30 minutes post landing. During boost, the heat sink capacity of the water supply will be utilized, without water boiler operation, with a resultant increase in bulk water temperature of approximately 10F (6C).

The RTG cooling kit can be located either forward or aft in the cargo bay. Adequate space exists at either location although added structural support points may be required. Basic system schematics are shown in Figure 3-7 for each location. Ground coolant lines interface with lines from the kit and isolation valving allows selection of the desired cooling mode. The kit interfaces with the Orbiter at the Station 1307 bulkhead for the two ground coolant lines and the steam vent line.

On considering the effect of kit location on the Orbiter, an aft location minimizes length of the three-inch (7.6 cm) diameter steam vent line while the remaining water supply line lengths and number of components are not significantly affected by kit location. The Orbiter center of gravity is shifted aft by approximately eight inches (20 cm), assuming an empty Tug after a deployment mission, with an aft mounted RTG kit weighing 900 pounds (408 kg). The resulting CG remains within the required envelope for Orbiter entry through landing. No relative effect on Tug or payload could be established for aft versus forward location of the kit.

GROUNDRULES:
- DUMP THROUGH TUG VIA AFT UMBILICAL TO AVOID ORBITER CONTAMINATION
- SEQUENTIAL DUMP OF BIPROPELLANTS IN 150 SEC EACH
- MONOPROPELLANT DUMP IN 300 SEC
- MULTISTAGE TANKS ARE MANIFOLDED WITHIN PAYLOAD

OPTIONS:

DUMP OPTIONS	LINE DIA IN. (cm)	INST WT LB (kg)	ADDED INTERFACES			
			ACTIVE		PASSIVE	
			GROUND	FLIGHT	GROUND	FLIGHT
1. ALL PAYLOADS	1 (2.54)	75 (36)	2	6		2
2. ~95% OF PAYLOADS (<400 LB (181 kg) MONO PROP)	≤0.5 (≤1.27)	21 (9.5)	1	3		1

RECOMMENDATION: NO PROPELLANT ABORT DUMP

- 95% OF PAYLOADS HAVE LESS THAN 400 LB (181 kg) OF MONOPROPELLANT
- NO SAFETY PROBLEM OTHER THAN STRUCTURAL FAILURE IDENTIFIED
- DESIGN TANKS & ATTACHMENT FOR 9g CRASH
- PL-01-A HAS APPROX 4,000 LB (1,810 kg) BIPROP. IN MULTISTAGES; PROVIDE KIT TO DUMP VIA AFT BULKHEAD UMBILICALS & ROUTE DUMP LINES DIRECT FROM PAYLOAD TO STA 1307 (IF DUMP IS DESIRED)

Figure 3-8. Payload Propellant Abort Dump

It is recommended that the kit be located aft to minimize steam vent line length and that the steam be vented through a nozzle mounted on the Orbiter firewall. If the kit grows substantially in weight, the aft cg shift may dictate mounting of the kit forward to stay within the required axial cg envelope.

3.2.1.3 Propellant Abort Dump. The options considered for this evaluation are shown in Figure 3-8 in conjunction with assumed ground rules and the resulting recommendation.

In sizing lines for payload propellant dump, it was assumed that dump would be aft directed to minimize Orbiter contamination potential. Monopropellants were assumed to dump in 30 seconds and bipropellants in 150 seconds sequentially. GN_2 can be dumped into the cargo bay with no hazard to the Orbiter.

The maximum propellant load for PL-01-A can be dumped in the required time with a one-inch (2.54 cm) line while the majority of payloads, utilizing N_2H_4, require only a 0.5-inch (1.27 cm) line.

Evaluation of the safety aspects, which are the controlling criteria for whether dump is required at all, disclosed no safety hazards other than propellant tank/supports structural failure under crash load conditions. The mere presence of storable propellants in an abort situation does not present an identifiable hazard and the quantities do not appreciably affect the Orbiter abort cg location.

It is recommended that Tug payloads, which in most cases carry less than 400 pounds (182 kg) of propellant, be designed to sustain crash loading conditions. It is possible

Table 3-7. Payload Fluids Interface Recommendations

PAYLOAD FUNCTION	RECOMMENDATION	INTERFACES		COMMENTS
		TUG	ORBITER	
PROPELLANT FILL & DRAIN	ACCOMPLISH IN PAYLOAD CHANGEOUT ROOM	NO	NO	NO SAFETY CONCERN IDENTIFIED
PROPELLANT VENT	N_2H_4 VIA TUG; KIT OTHER PROPELLANTS DIRECT TO ORBITER	YES	EXISTING	CONNECT INTO EXISTING TUG RCS VENT LINE
PROPELLANT ABORT DUMP	NO DUMP	NO	NO	DESIGN TANKAGE TO CRASH LOADS (MAYBE ADD DIRECT-TO-ORBITER KIT FOR LARGE TANKAGE)
PRESSURANT FILL	ACCOMPLISH IN PAYLOAD CHANGEOUT ROOM	NO	NO	MINIMUM INTERFACES
PRESSURANT VENT	VENT DIRECTLY INTO PAYLOAD BAY	NO	NO	MINIMUM INTERFACES
BATTERY VENT	THROUGH TUG	YES	EXISTING	CONNECT INTO TUG BATTERY VENT LINE
LIQUID HELIUM FILL & DRAIN	DIRECT TO ORBITER PANEL AT STA 835 (FILL IN PCR)	NO (NO)	YES (NO)	TOP UNTIL T-4 HR
LIQUID HELIUM VENT/DUMP	NO DUMP; VENT DIRECTLY INTO PAYLOAD BAY	NO	NO	MINIMUM INTERFACES
COOLING (RTG)	WATER BOILER IN AFT CARGO BAY	NO	YES	REMOVES STEAM VENT LINE FROM BAY
CLEANLINESS	DIRECT TO ORBITER VIA STA 835 PANEL	NO	YES	ALSO REQD FOR NON-TUG PAYLOADS

that a relatively small percentage of payloads, such as PL-01-A, will incur unacceptable weight penalties by designing for crash loads. For those payloads, it is recommended that a kit be provided to route dump lines from the payload, through an inflight disconnect at the payload or adapter, and aft through the cargo bay to Station 1307 propulsive payload panels.

3.2.2 FLUID SERVICE RECOMMENDATIONS. A listing of payload interface recommendations for fluids and gases is included in Table 3-7 for each identified functional requirement. This table summarizes recommendations and rationale from the previous detailed charts and the additional information contained in Appendix A. Figure 3-9 shows the recommended routing for the fluid umbilical kits identified in Table 3-7.

3.3 AVIONIC SERVICES ACCOMMODATIONS TRADE

The avionics service implementation trade study employed the approach shown in Figure 3-10 to obtain detailed routing recommendations.

In addition to the SSPD data used to establish levels of support, two other sources were used to obtain detailed avionic interface data. Interface requirements based on "composite" spacecraft needs were obtained from the MDAC Payload Utilization

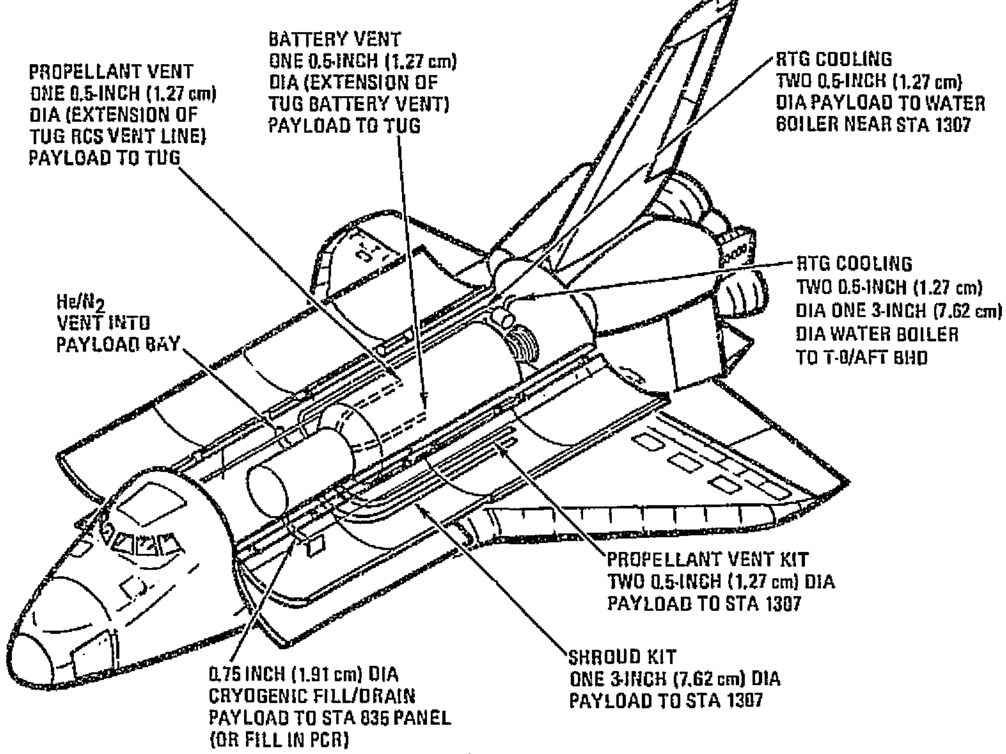


Figure 3-9. Payload Fluid Services Routing Recommendations

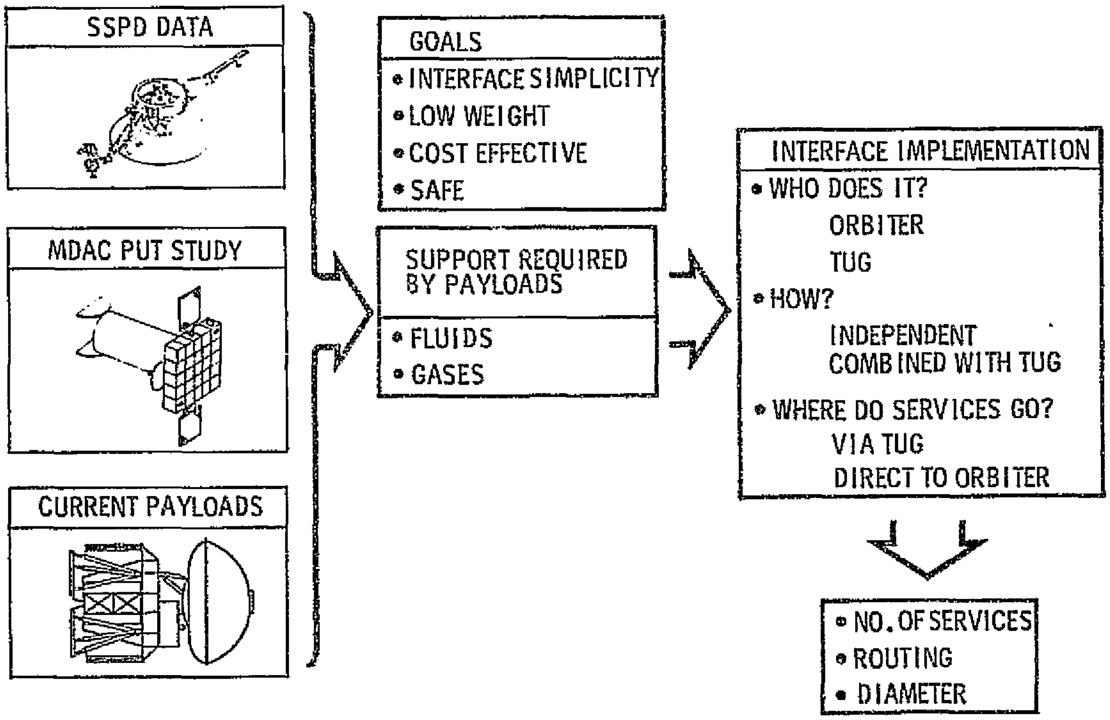


Figure 3-10. Avionic Services Implementation Approach

for Tug (PUT) study (Reference 3-1) and the exchange of preliminary data from their IUS/Tug Payload Requirements Compatibility study (Reference 3-2). Specific interface requirements obtained from Viking were used as typical complex spacecraft requirements for comparison purposes with the PUT data.

Once the service requirements were defined, analyses were conducted to determine the best method of accommodating these services. Important considerations used during this evaluation were:

Who does it?	Is the service satisfied by the Tug or the Orbiter? If the Orbiter potentially provides the service, the Tug must be considered only for its service transmission acceptability.
How is it transmitted?	Do all functions have to be individually hardwired, or may some data be interleaved and multiplexed?
Where are wires routed?	Should they go completely through the Tug, partially through Tug, or direct from payload to Orbiter?

Resulting interface requirements were then investigated for reasonable methods of implementation.

3.3.1 SERVICE ALLOCATION RECOMMENDATION. Payload service functions may be allocated either to the Orbiter or to the Tug for implementation. The decision logic used to determine this allocation for this trade study is shown in Figure 3-11. If the Tug is required to provide a service to the spacecraft during both: 1) Orbiter ascent through deployment, and 2) after Tug/spacecraft deployment from the Orbiter, then this service was allocated to the Tug. If this service is only required during Orbiter ascent through the Tug/spacecraft deployment phase, it is allocated to the Orbiter for implementation.

Application of this logic to the Tug class of payloads indicates that:

a. Spacecraft requirements involving data storage and computer support (data management) are best satisfied by Orbiter capabilities, and

b. Spacecraft requirements involving power and data transfer may be implemented via Tug capability. During Tug/spacecraft pre-deployment from the Orbiter phases, for example, the Tug may receive power from the Orbiter and would transfer part of this power on to the spacecraft using the same Tug/spacecraft interface employed during Tug flight operation.

3.3.2 IMPLEMENTATION CONSIDERATIONS AND ANALYSIS. To factor in current payload interface approaches two additional sources were used to obtain detailed avionic interface data. Interface requirements based on "composite" spacecraft needs were obtained from the MDAC Payload Utilization for Tug (PUT) study (Refer-

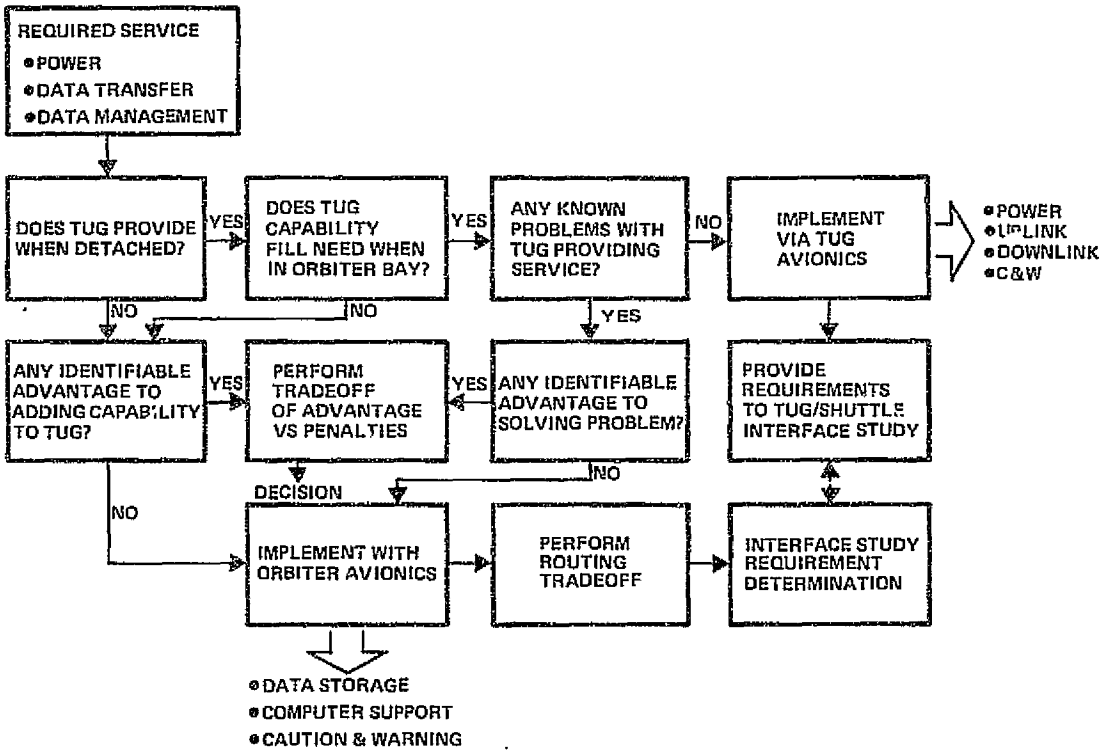


Figure 3-11. Payload Service Allocation to Tug or Orbiter

ence 3-1) and the exchange of preliminary data from their IUS/Tug Payload Requirements Compatibility study (Reference 3-2). Additionally, specific interface requirements obtained from Viking were used as typical complex spacecraft requirements for comparison purposes with the PUT data.

Resulting interface requirements were then investigated for reasonable methods of implementation. Performance considerations and the resulting effects on alternative interface implementation techniques that were taken into account are:

Considerations	Implementation
Safety	C&W Philosophy, redundancy
Status	Routing, data processing
EMI	Coax, TSP, grounding
Weight	Multiplex versus direct wired
Simplicity	Service panel size, wire count
Power	Noise, routing, capability
Reliability	Redundancy, Tug/Orbiter equipment allocation

Table 3-8. Tug Payload Interface Requirements

Function	To Tug	To Orbiter	To GSE
Commands	86		
Monitors	343	318	316
Power and Excitation	40	16	20
Communication Links			
Uplink	4	4	4
Downlink	2	2	2
Video	2	2	2
Total Interface Pins Required	497	342	344
(All signals hardwired)			

A review of the results of the PUT study plus an update by MDAC personnel at a data exchange meeting between MDAC and GDC resulted in the data shown in Table 3-8. This shows that approximately 500 pins are required across the Tug/payload interface if direct wire techniques (no multiplexing) are used. This data contains no distinction between safety functions and mission status signals, and shield wires are not considered.

Table 3-8 shows the spacecraft interfaces to Tug, Orbiter, and GSE. Approximately 340 interface pins are required to throughput analog, power, video, downlink, uplink, and caution and warning data to GSE via Tug/Orbiter/GSE interfaces. During ascent, downlink, uplink, and caution and warning data are transmitted via 340 Tug and Orbiter interfaces. During Tug/spacecraft flight outside of the Orbiter approximately 170 pins are required across theTug/spacecraft interface.

To confirm the type of data that must be transmitted across the payload interface and provide a valid data point for comparison with the PUT data, several current payloads were investigated. These included Viking, MVM, Intelsat, Helios, and MJO. The number of pins and functions provided were determined from interface drawings of these payloads. The data was modified to reflect the difference between operating these payloads on an expendable launch vehicle and in the Shuttle payload bay. The following data identifies the discretes required from payload to Tug/Shuttle but without the redundancy that the Shuttle system will demand:

Payload:	Viking	MVM	Intelsat	Helios	MJO
No. of Pins:	102	59	20	16	76

From these data the Viking was selected as the worst case since it has the most complex interface.

Table 3-9. Estimated Interface For a Viking Type Payload

Function	To Tug	To Orbiter	To GSE
Commands	6	7	15
Monitors	6	30	45
Power and Excitation	21	9	24
Communication Links			
Uplink			
Downlink	2	2	2
Video			
Total Interface Pins Required	35	48	86

The 102 pins for the Viking payload have various functions and destinations as shown in Table 3-9, i.e., 35 to Tug, 48 to Orbiter and 86 to GSE. Some wires go to more than one destination. This data showed good agreement with the (non-redundant) number of pins given in the PUT study for Shuttle payloads. It was concluded from this comparison that the number of pins and interface functions assumed in Table 3-8 were realistic for this interface study.

Because the preceding data indicate that a significant interface (in terms of size and weight) results from Tug/payload/Orbiter integration using hardwires for spacecraft interfaces, the effect of multiplexing and umbilical routing variations was investigated. It was determined that significant payload weight savings could be achieved by employing multiplex techniques for both uplink and downlink signals. These results are indicated in Table 3-10 for two routing configurations: Tug forward disconnect (method 2), and via Tug deployment adapter (method 1), and with and without multiplexing of 75% of the compatible signals. These routing techniques are shown in Figure 3-12. The power, excitation, and high frequency signals are not compatible with the multiplexing scheme under consideration.

Table 3-10. Payload Penalty vs Routing/Signal Multiplexing

Method	Multiplex (75% TSP)	Via Deployment Adapter	Via Tug Forward Disconnect	Payload Penalty (pounds)
2 M	Yes	No	Yes	0
2 D	No	No	Yes	76
1 M	Yes	Yes	No	151
1 D	No	Yes	No	373

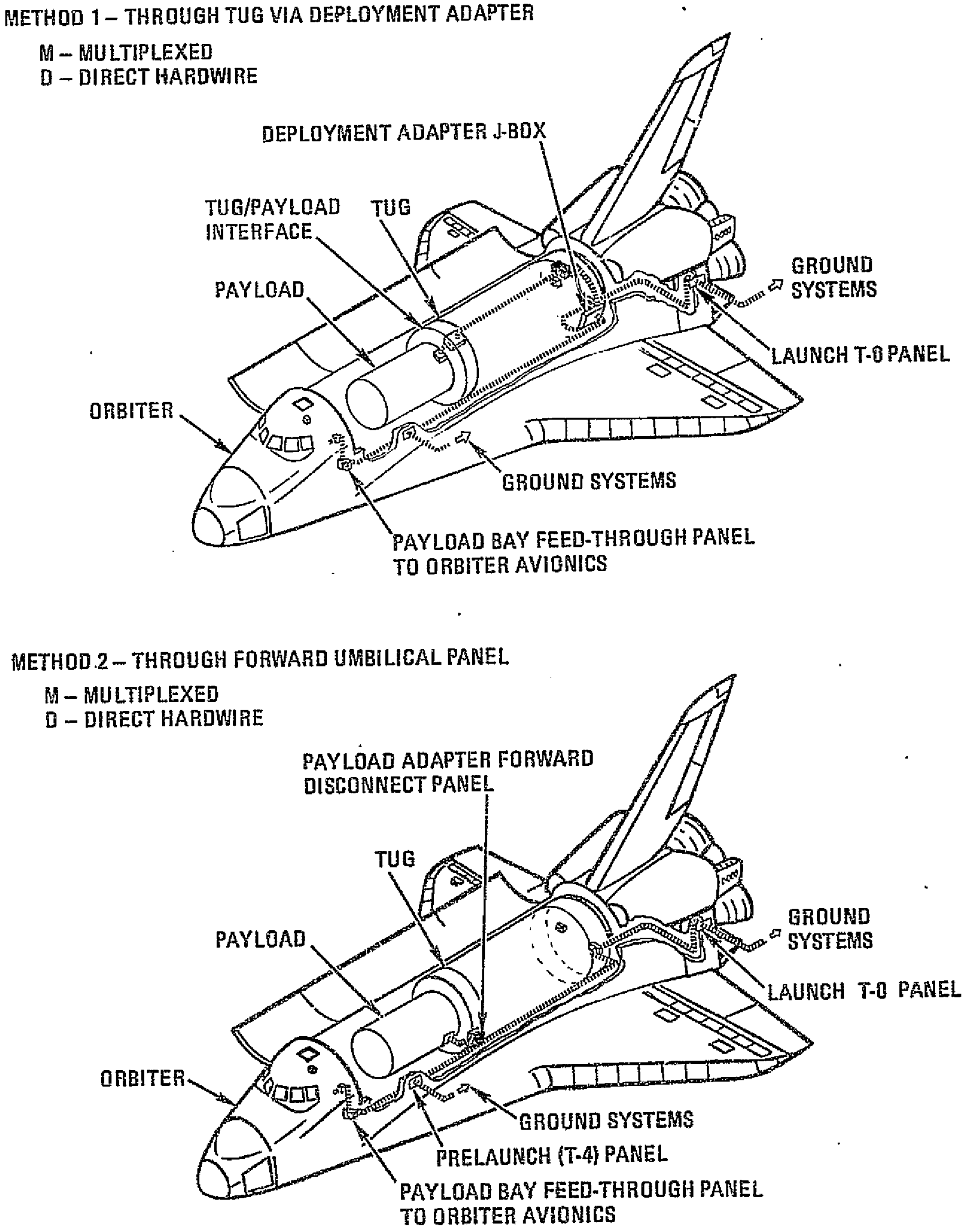


Figure 3-12. Electrical Service Routing Techniques

Using the foregoing models of cabling methods, with and without multiplexing, cable weights for the major cable segments were calculated. For these weights, equivalent Tug performance penalty was obtained using -2.62 and -0.36 as the payload weight partials for the Tug and Orbiter respectively. For this analysis only the No. 22 twisted shielded pair and the No. 6 power cable weights were calculated since they account for about 97% of the total weights. The net penalties were:

Method	Penalty, pounds	(kg)
1D	442	200
2D	145	66
1M	220	100
2M	69	31

This data normalizes to the penalty of method 2M (Tug forward disconnect/multiplexed) to show the net penalty incurred by selection of other methods.

In conclusion, it is seen that due to redundancy requirements and multiple payload requirements, a relatively small number of payload service functions (including data links, monitor and control discretes, analog data, and power) may require the implementation of a relatively large interface umbilical to Tug, Orbiter, and GSE.

Several recommendations that could reduce the size of this interface, and result in Tug/Orbiter weight savings and smaller more compact umbilical interface mechanism requirements are:

a. Differentiate between safety critical and mission critical functions.

b. Multiplex nonsafety critical functions, for example:

   1. Tape recorder status.

   2. Battery charge command.

   3. TV C/O command.

c. Wire direct and multiplex (back-up) safety critical functions, for example:

   1. Pressure vessels temperatures/pressures.

   2. RTG unit temperatures.

   3. Arm/safe function status.

d. Disable groups of payload safety functions while in Orbiter payload bay by power bus arm/safe technique, for example:

   1. Tug/payload deployment/separation commands.

   2. Propellant valves/control commands.

   3. Payload structural deployment functions (solar panels etc.).

These recommendations were transmitted through MSFC to the MDAC payloads study for their consideration in simplifying the Tug/payload and Tug/Orbiter interfaces. Subsequent scrutiny of payload requirements by the payloads study resulted in several recommendations for service level provisions and routing needs.

a. Multiplexing can be used to advantage by Tug payloads to reduce direct hardwire requirements to 35 caution and warning signals. This represents a multiple Tug/payload requirement.

b. It is desirable for most payloads to route uplink, downlink, and caution and warning hardwires through Tug and deployment adapter. This routing implementation allows early integration and verification of avionic interfaces, and potentially reduces payload/peculiar integration tasks.

c. Forward panel routing is still a viable and desirable option for scientific payloads requiring significant ground prelaunch or in flight Orbiter support.

The accommodation implementations of avionics and fluids requirements contained in the following summary reflect these payload recommendations.

3.4 PAYLOAD INTERFACE REQUIREMENTS SUMMARY

The results of the payload services accommodations trade are graphically displayed in Figure 3-13 and shown in greater detail in Table 3-11. Power and caution and warning signals are routed through (or supplied by) Tug, while fluid services are generally routed direct to the Orbiter through a forward-mounted Tug umbilical panel. The Tug-mounted panel was selected to standardize this interface, since direct Orbiter-to-payload umbilicals would be nonstandard due to payload geometry variations.

3.5 REFERENCES

3-1. Payload Utilization of Tug, Contract NAS8-29743, McDonnell Douglas Corp.

3-2. IUS/Tug Payload Requirements Compatibility Study, Contract NAS8-31013, McDonnell Douglas Corp.

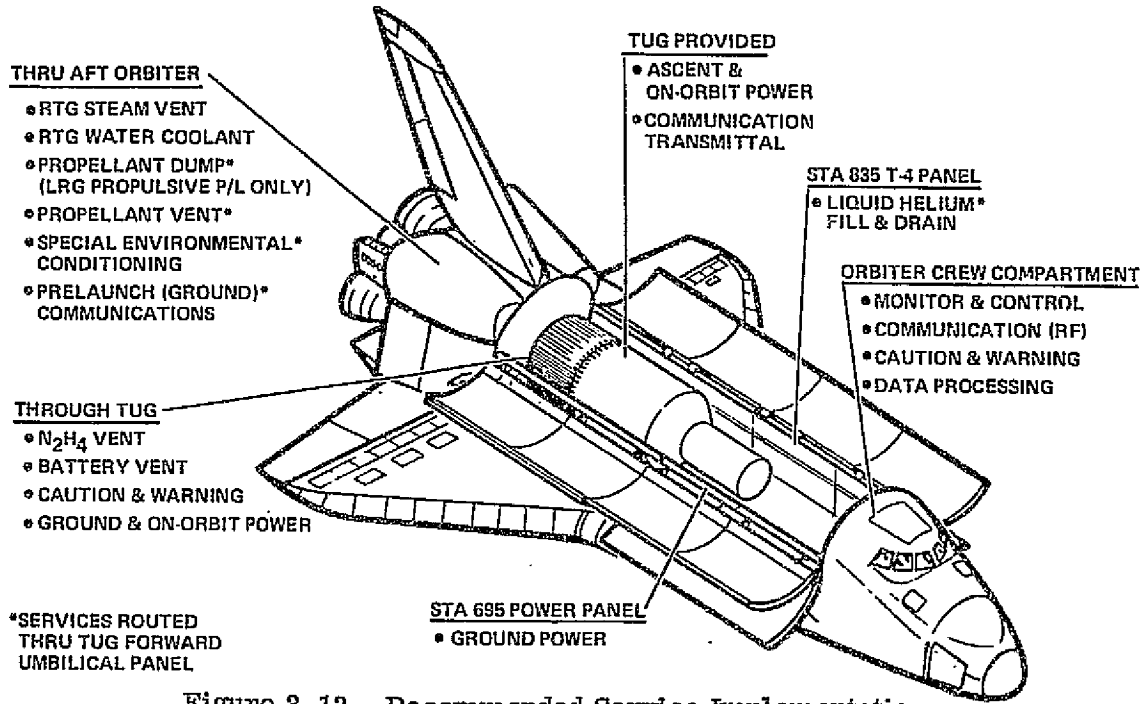


Figure 3-13. Recommended Service Implementation

Table 3-11. Payload Service Accommodations

Payload Function	Service Level	Accommodation	Interface Tug	Interface Orbiter
Prop. F&D	~ 0.5 in. (1.27 cm) dia. each prop.	Remote	No	No
Abort Dump	< 500 lb (227 kg)	Self contain	No	No
	>> 500 lb (227 kg)	Overboard dump kit	No*	Yes
Vent	~0.5 in. (1.27 cm) dia N_2H_4 prop.	Integrate w/Tug RCS vent	Yes	Existing
	~0.5 in. (1.27 cm) dia each other prop.	Overboard vent kit	No*	Yes
Press Fill	~0.25 in. (0.64 cm) dia	Remote	No	No
Vent	~0.25 in. (0.64 cm) dia	Into cargo bay	No	No
Battery Vent	~0.5 in. (1.27 cm) dia	Integrate w/Tug bat. vent or self contain	Yes	Existing
LHe F&D	~1.0 in. dia (2.54 cm)	Direct to 835 T-4 panel	No*	Yes
Vent	~1.0 in. dia (2.54 cm)	Into cargo bay	No	No
RTG Cooling	~0.5 in. (1.27 cm) dia H_2O inlet/outlet	Thermal control unit	No	Yes
	~3.0 in. (7.62 cm) dia steam vent	(water boiler) kit	No	Yes
Shroud Repress	No known	Payload autonomous	No	No
Conditioning	~3.0 in. (7.62 cm) dia class < 5000 GN_2	Direct to Orbiter	No*	Yes
Communication	2 KBS up 51 KBS down	Via Tug avionics	Yes	Yes
Caution & Warning	35 signals	Through Tug	Yes	Yes
Data Processing	Storage & Computation	Orbiter supplied	No	Yes
Power	700 W ground & on-orbit 600 W ascent	Orbiter 695 panel via Tug From Tug fuel cell	Yes Yes	Yes No

* Assumes forward umbilical panel

SECTION 4

TUG INTERFACE ANALYSES AND TRADE STUDIES

The Tug subsystem interface analyses task provided the technical data, trade studies, and screening process to translate functional interface requirements into firm, realistic Space Tug/Orbiter detailed interface requirements. Typical Shuttle interfaces used for Space Tug accommodation are identified in Figure 4-1. These interfaces are primarily involved with supporting and servicing the Tug during launch countdown and in flight, deploying and retrieving the Tug on orbit, and maintaining control over the Tug when it is in or near the Orbiter. Each of these interface areas is investigated in this section to determine the best method of accomplishing the functions required, with an overriding goal of establishing simple-flexible Orbiter interface requirements suitable for Tug, Tug payloads, and other Orbiter payloads.

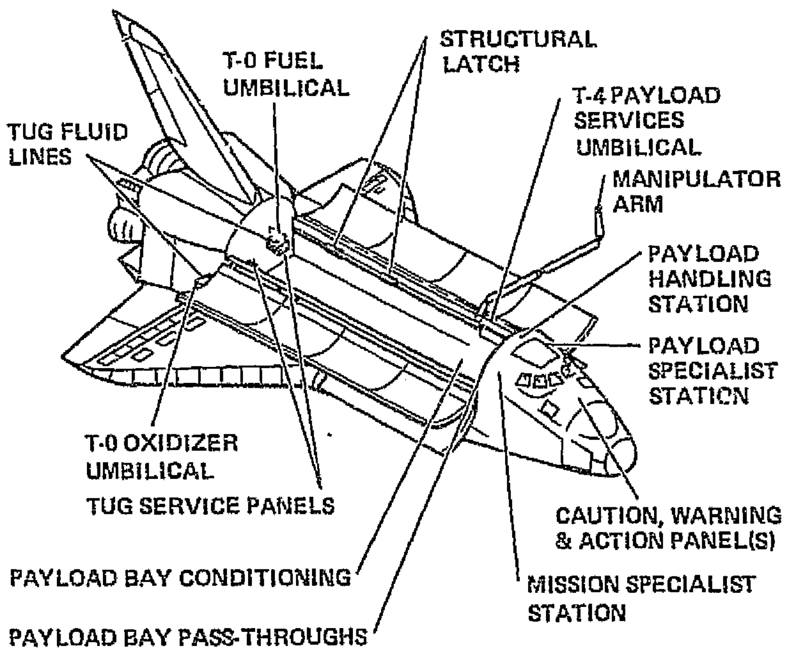


Figure 4-1. Tug-Related Orbiter Interface Provisions

Combined Tug/Payload functional interface requirements obtained from Sections 2 and 3 were investigated on a subsystem basis to fully understand the functions of each device or operational action and thereby determine its detail interface requirements. In addition to interface analyses for the MSFC baseline Tug, alternative interface

concepts were investigated. The subsystem interfaces were grouped into six categories by technical discipline as shown in Figure 4-2. A detailed description of these six disciplines is contained in Section 4-2 through 4-7 of this report.

SUBSYSTEM	ACCOMMODATION
STRUCTURAL	SUPPORT & HANDLING
MECHANICAL	DEPLOYMENT/ RETRIEVAL
FLUID	SERVICES & ABORT DUMP
ENVIRONMENTAL	CONDITIONING & PURGES
AVIONIC	MONITOR & CONTROL
SAFETY	CAUTION & WARNING

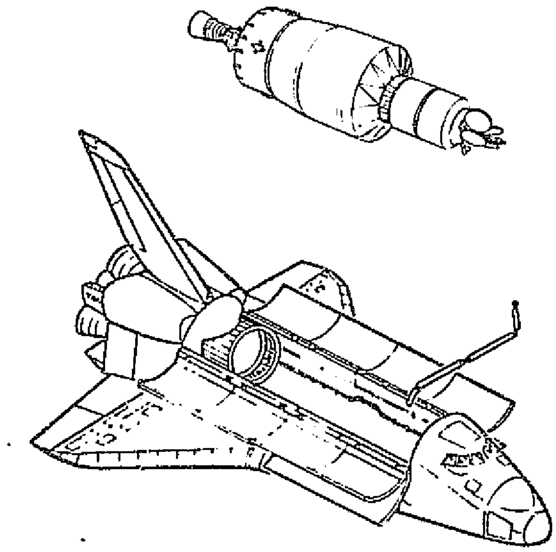


Figure 4-2. Interface Subsystem Categories

Section 4.1 provides initial visibility of the alternative interface system concepts considered and their importance to the independent subsystem trades. Evaluation criteria used in the trades are also discussed.

4.1 INTERFACE CONCEPT DEFINITION AND EVALUATION

The approach employed to perform the Tug plus Tug payload-to-Orbiter interface analysis is described as follows.

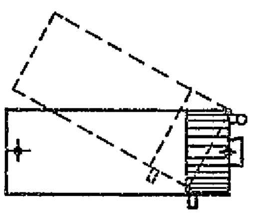
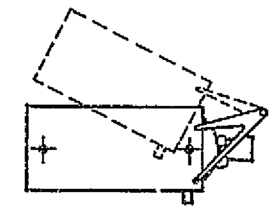
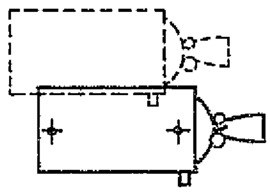
Starting with the full range of functional/operational requirements that must be satisfied by each Tug/Payload/Orbiter interface element obtained in Sections 2 and 3 (structural attachment, fluid line), the objectives of this task are to:

a. Identify alternative interface concepts capable of satisfying the established functional/operational requirements.

b. Evaluate the options via trade studies to determine which best accomplish subsystem functional requirements.

4.1.1 SUPPORT/DEPLOYMENT CONCEPTS. Alternative interface concepts investigated include direct Tug/Orbiter structural support and corresponding deletion of the deployment adapter. While identified as a structural trade, a support philosophy revision of this magnitude also affects other interface subsystems. The interface concept chart shown in Table 4-1 indicates the range of structural support concepts to be considered and their influence on other viable subsystem options.

Table 4-1. Tug/Orbiter Interface Concepts Subsystem Effect

	Interface Concepts		
Subsystem Effects	DEPLOYMENT ADAPTER 	ROTATION AID 	NONROTATING 
Structural	Adapter provides axial load distribution: results in lightest Tug & heavy peripheral equipment	Direct attachment results in beef-up of Tug frames, longerons & skin; i.e., heavy Tug	Direct attachment results in beef-up of Tug frames, longeron & skin; i.e., heavy Tug
Mechanical	Adapter Provides: • Rotation alignment -- rot. actuator optional • Docking alignment • Latching interface • Umbilical disconnect capability (before or after rotation) RMS optional for withdrawal, initial capture & insertion Results: Tug adapter responsible for many complex mech. functions	Aid Provides: • Rotation alignment – rot. actuator optional Optional provisions: • Peripheral equip. or part of Tug structure • Docking alignment • Capture latches • Umbilical disconnect RMS optional for withdrawal, initial capture, fine alignment Results: Orbiter RMS responsible for more deploy retrieve mech. functions	Tug peripheral equipment provides. • Umbilical disconnect Orbiter Provides. • RMS removal from payload bay • RMS initial capture • RMS fine alignment for insertion • Structural latching Results: Orbiter responsible for all mechanical functions except umbilical disconnect
Fluid	Adapter Provides: • Capability for fluid connection through rot. • Mounting for abort helium bottles, control valves, etc.	Aid Provides: • Capability for fluid connection through rot. Helium supply, valving, etc. in P/L bay aft bhd.-mounted equip. racks	Fluid umbilicals must be released before any motion. Helium supply, valving etc., included in P/L bay aft bhd.-mounted equip. racks
Environmental	Enclosed adapter may be used as controlled conditioning volume	No special engine system protection	No special engine system protection
Avionics	• Adapter provides convenient mounting for interface electronics • Hardware connection maintained through rot.	• Interface electronics included in P/L bay aft bhd.-mounted equip. racks • Capability to maintain hardwire connection through rot.	• Interface electronics included in P/L bay aft bhd.-mounted equip. racks • Hardwire umbilical must be released before any motion
Peripheral	One large, fairly complex piece of equipment integrates all payload bay support requirements. Minimizes demands on Orbiter for Tug support.	Small, relatively simple alignment device plus equipment racks & umbilical retraction device	Equipment racks and umbilical retraction device. Maximizes demands on Orbiter for Tug support

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The Deployment Adapter concept includes a support/deployment adapter. It distributes Orbiter attach fitting point loads into the Tug shell and provides positive positioning during initial deployment, alignment for docking, and is a convenient mounting place for Tug peripheral equipment (avionics, abort helium supply). Use of this adapter results in a clean Tug-to-Orbiter interface and maximizes Tug performance capability.

The Nonrotating concept eliminates the support adapter and its attendant load distribution and relatively complex deployment, retrieval, rotation, and latching functions. Orbiter attachment fitting point loads are taken directly into the Tug shell, requiring frame beefup and resulting in a general Tug weight increase. Rotation is eliminated: deployment/recovery is accomplished linearly with the manipulator, or other Orbiter-supplied aid as similarly proposed for the Large Space Telescope. Support equipment previously located in the deployment adapter is mounted to the payload bay in racks. Payload loss due to increase in Tug structural weight is partially compensated by addition of Tug propellant. This takes advantage of the greater Tug allowable weight (based on 65,000-lb (29,250 kg) Orbiter capability) due to adapter deletion, and helps defray the decrease in Tug performance capability.

The Rotation Aid concept is a compromise configuration. Orbiter fitting loads are taken directly by the Tug structure as in Nonrotating but a non-flight-loadcarrying rotation yoke is incorporated to aid in deployment, docking, and retrieval.

Each subsystem effect listed for the alternative support/deployment concepts must be considered in sufficient depth during the subsystem evaluation (Sections 4.2 through 4.7) to provide adequate information for subsequent system concept evaluation.

4.1.2 TRADE EVALUATION CRITERIA. Evaluation of alternative interface concepts will be accomplished by trade and optimization studies to determine Tug/Payload detailed subsystem interface requirements. Trade studies will evaluate subsystem interface options using several criteria. Table 4-2 identifies these trades and evaluation criteria. Cost, weight, performance, and reliability were evaluated quantitatively. Safety, risk, and interface simplicity were evaluated qualitatively. Safety was an absolute criterion. In most areas, interface simplicity and reliability were the more significant criteria. Interface cost (DDT&E) and performance effects were less significant since, in most cases, their contribution to total system cost and performance was relatively small. Evaluation criteria methodology is contained in the following paragraphs.

Cost Analysis. Cost methodology involved the use of carefully screened cost data to build estimates at the detail task level and grouping task elements to provide major functional level costs. Each level of cost buildup was compared with analogous or parametric data as a check to ensure that the detail estimates properly include the total task. Accurate and comprehensive cost data was generated and used as an interface option evaluation criterion. Cost details are included in Volume VI of this final report.

Table 4-2. Trade and Optimization Studies

SUBSYSTEM & OPTIMIZATION TRADES	EVALUATION CRITERIA
STRUCTURAL INTERFACE OPTIMIZE STRUCTURAL ARRANGEMENT FITTING ARRANGEMENT COMPARISON DETERMINATE VS. REDUNDANT TUG SUPPORT METHOD COMPARISON (FUNCTIONAL ELEMENT ARRANGEMENTS)	• COST • WEIGHT
MECHANICAL INTERFACE DEPLOYMENT ROTATION OPTIMIZATION UMBILICAL PANEL ACTUATION RMS SOCKET LOCATION DOCKING ALIGNMENT	• RISK
FLUID INTERFACE ORBITER VS. TUG-MOUNTED FLUID CONTROLS DISCONNECT BEFORE OR AFTER ROTATION RTLS ABORT DUMP LINE SIZING ON-ORBIT PROPELLANT DUMP METHOD HYDROGEN DUMP VS. NO HYDROGEN DUMP	• SAFETY/RELIABILITY • PERFORMANCE
ENVIRONMENTAL INTERFACE GROUND CONDITIONING SPECS PAYLOAD BAY CONDITIONING CONTROL	• INTERFACE SIMPLICITY
AVIONICS INTERFACE MACS ALLOCATION (TUG/ORBITER) CREW STATION ALLOCATION (EQUIPMENT/FUNCTION) MAN-MACHINE INTERFACE EFFECTIVITY	• MANNED COMPATIBILITY

Weight. The main output of the mass properties effort consisted of delta weights for interface design trades. This data was used primarily to generate performance capability changes. Center-of-gravity effects were also determined for those trades that have a significant impact on Tug and Shuttle Orbiter longitudinal centers of gravity.

Risk. Relative risk among options was determined. Since risk included areas of potential failure, the risk assessment identified both the probability of failure and and consequences of failure (e.g., mission abort, schedule delay, cost overrrun, hazard to crew). The potential risk of one option versus another was judged by delta cost, delta schedule, and delta reliability.

Safety/Reliability. Criteria was established in Sections 2 and 3 for Tug and payloads, respectively, and interface options assessed as discussed in Section 4.7.

Performance. Payload partials with respect to Tug burnout weight and Shuttle interface accommodations were calculated for the baseline Tug and used to obtain performance differences.

Interface Simplicity. This criterion was evaluated in terms of number of interface elements, ease of operation during installation and functional operation, and mechanical complexity.

4.2 STRUCTURAL SUPPORT INTERFACE

The structural support system consists of structural elements connecting the Tug or any of its associated subsystems to the Orbiter or its associated AGE during any phase of ground and/or flight operations. The major structural elements are the interface fittings (at points of primary structural support), any "position control" structure (such as the support/deployment adapter or rotation aid discussed in Section 4.1.1), and any dedicated umbilical support provisions. Other structural elements include fittings for Orbiter RMS attachment, additional primary supports for ground handling and transportation (if required), and local supports for interface elements and peripheral equipment in the mechanisms, avionics, fluids, and environmental subsystems.

In the study the configuration and interface requirements of each element had to be defined in sufficient detail to describe accurately an integrated structural support system satisfying two related objectives:

a. To ensure Tug/Orbiter physical and functional compatibility.

b. To minimize the impact, in terms of weight, performance, dynamic response, schedule, cost, reliability, safety, and complexity, on the Tug and Orbiter vehicles and on all associated ground and flight operations.

These objectives were met by addressing the following key issues:

a. In addition to the baseline Tug, what other structural arrangements offer potential interface benefits?

b. Which ones merit detail design and comparison with the baseline Tug?

c. What structural arrangement is preferred? To what extent must the baseline be revised?

d. What are its interface requirements? To what extent are they incompatible with the current baseline Orbiter?

To define ultimately a specific set of structural interface requirements in detail, a preferred structural arrangement first had to be selected. This was accomplished through a process of identifying, evaluating, comparing, and deleting candidates until a single arrangement could be selected. Since attachment fitting locations vary with the support concept, a systematic approach was needed to assess suitably matched fitting/support system arrangements.

The major tasks in this process are identified in the flow chart of Figure 4.2-1. Input consisted of customer-supplied baseline data, preliminary subsystem data, and the

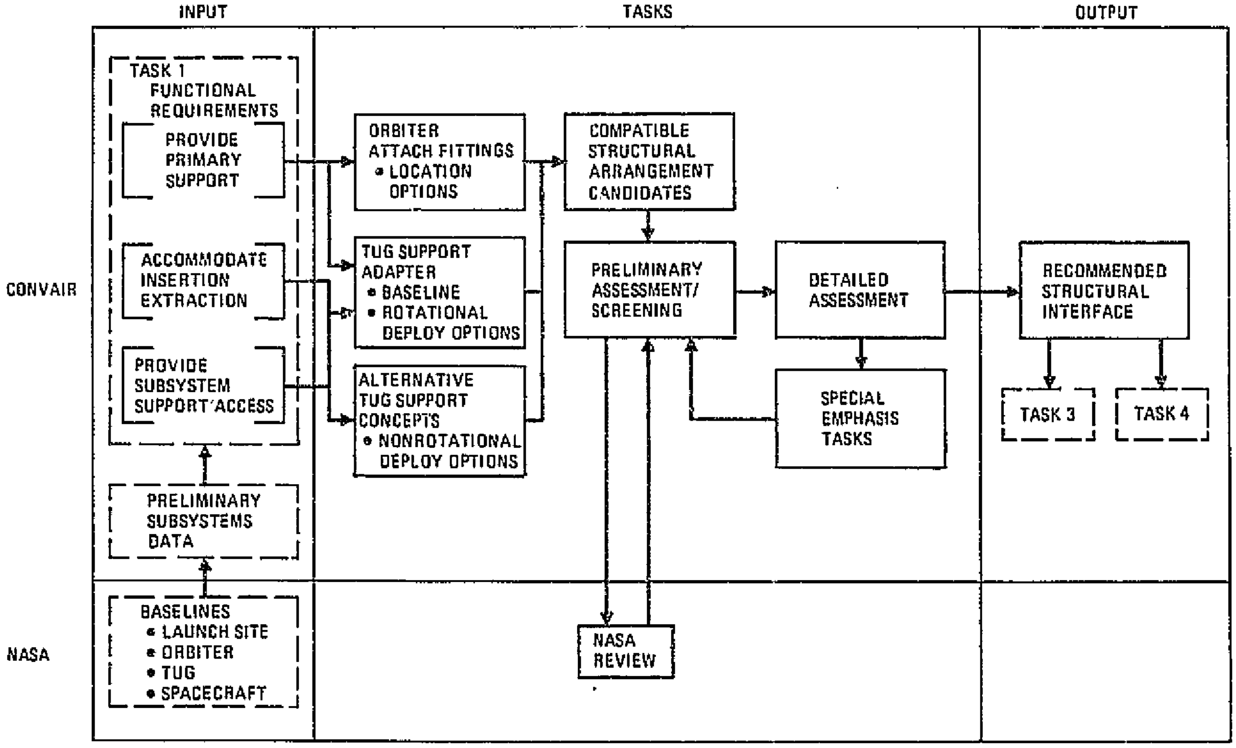


Figure 4.2-1. Task Flow, Structural Support Interface Analysis

Functional Requirements of Task 1. Individual fitting and support concept options were initially established, properly matched for system compatibility, and finally subjected to a two-stage assessment, including iterative update based on a series of special emphasis tasks, to obtain a recommended interface solution. Output consisted of detailed interface requirements for the recommended arrangement, supported by design data and the associated analyses (weight, stress, performance, dynamics). This data in turn served as input to Tasks 3 and 4.

<u>Functional Requirements.</u> As implied in Figure 4.2-1, the characteristics of each subsystem element represent design solutions satisfying one or more top-level functional requirement(s). In view of the baseline Orbiter discrete-point cargo support concept illustrated in Figure 4.2-2, the requirement to provide Tug primary structural support defined the need for a set of interface fittings at the discrete points of attachment between the Tug (and/or any adjoining load-carrying structure) and the Orbiter.

The requirement to accommodate Tug insertion into and extraction from the Orbiter defined the need for compatibility of the vehicle external configuration, the type and arrangement and location of structural elements, and the detail interface characteristics with the equipment and operations used for programmed Tug motion relative

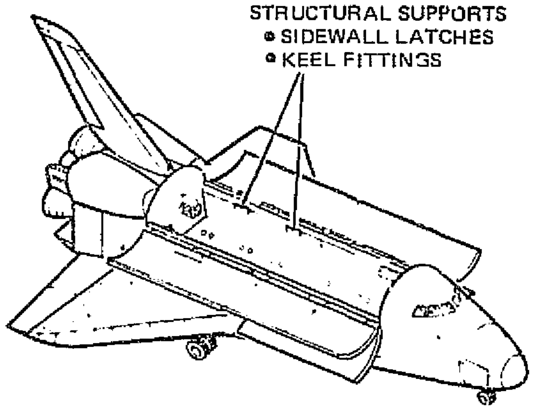


Figure 4.2-2. Orbiter Cargo Support Concept

to the Orbiter both at the launch site and on-orbit. The requirement to provide subsystem support/access defined the need for structural elements compatible with the installation, servicing, and functional requirements of the various subsystem components and peripheral equipment, which are carried within the Orbiter cargo bay but not attached to the Tug flight vehicle.

Orbiter Attachment Fittings. An analysis was conducted to identify candidate support fitting locations and arrangements. In addition to the NASA baseline Tug 6-point interface fitting arrangement and the 4-point arrangement selected during the STSS, others that offered potential reduction in reactions, dynamic response, complexity, or weight/configuration impacts were investigated.

Tug Support Adapter. The baseline concept employed a load-distributing structural shell and provided both position control during deployment and retrieval and convenient support for mechanical, fluid, and avionics peripheral subsystems. Preliminary structural design and analysis of the adapter was prepared. "Rotation aid" options eliminated the support adapter in favor of direct payload bay mounting but retained a non-load carrying position control structural element for alignment during deployment and retrieval.

Alternative Tug Support Concepts. Nonrotational deploy options were identified, which also employed direct payload bay mounting but eliminated dedicated position control elements entirely in favor of lateral deploy/retrieval using the Orbiter RMS only.

Compatible Structural Arrangement Candidates. The attachment fitting arrangements and Tug support concepts generated in the preceding tasks were integrated into physically and functionally compatible structural support systems. The resulting candidate support locations and arrangements are discussed in Section 4.2.2.1.

Preliminary Assessment/Screening. This task reduced the number of structural arrangements subjected to subsequent detail design investigation. The method and results are discussed in detail in Section 4.2.2.

Detailed Assessment. Preliminary design and analysis of the major structural interface elements (fittings, position control, subsystem support, and local Tug structure)

of each selected structural arrangement were conducted in this task, which is discussed in Section 4.2.3.

Special Emphasis Tasks. These tasks were conducted in response to items of concern resulting either from problems identified in the course of the study or from changes in requirements. Output was used to update results of earlier preliminary screening and detailed assessment tasks. This is reported in conjunction with the individual affected tasks in Sections 4.2.2 and 4.2.3.

Recommended Structural Interface. This task consisted of selecting the preferred Tug structural support concept and documenting its interface requirements. It is presented in Section 4.2.4.

4.2.1 GUIDELINES AND GROUND RULES. Performance of the structural support interface design/analysis tasks required the establishment of ground rules for the description of each vehicle element and for the definition of the pertinent imposed environmental conditions involved in the various investigations. Figure 4.2-3 identifies the primary ground rule categories and provides reference to the subsequent sections in which each is discussed in detail. International System (SI) units are included on all data generated in this study but have not been added to NASA data initially supplied without them.

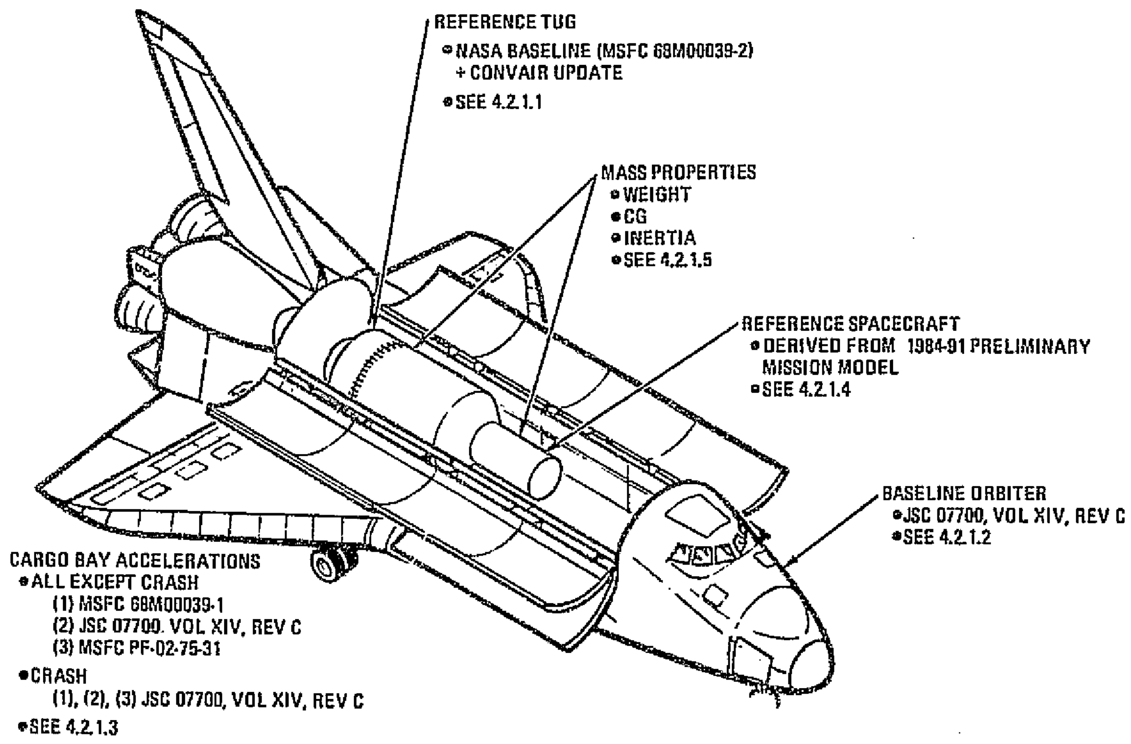


Figure 4.2-3. Primary Groundrule Categories

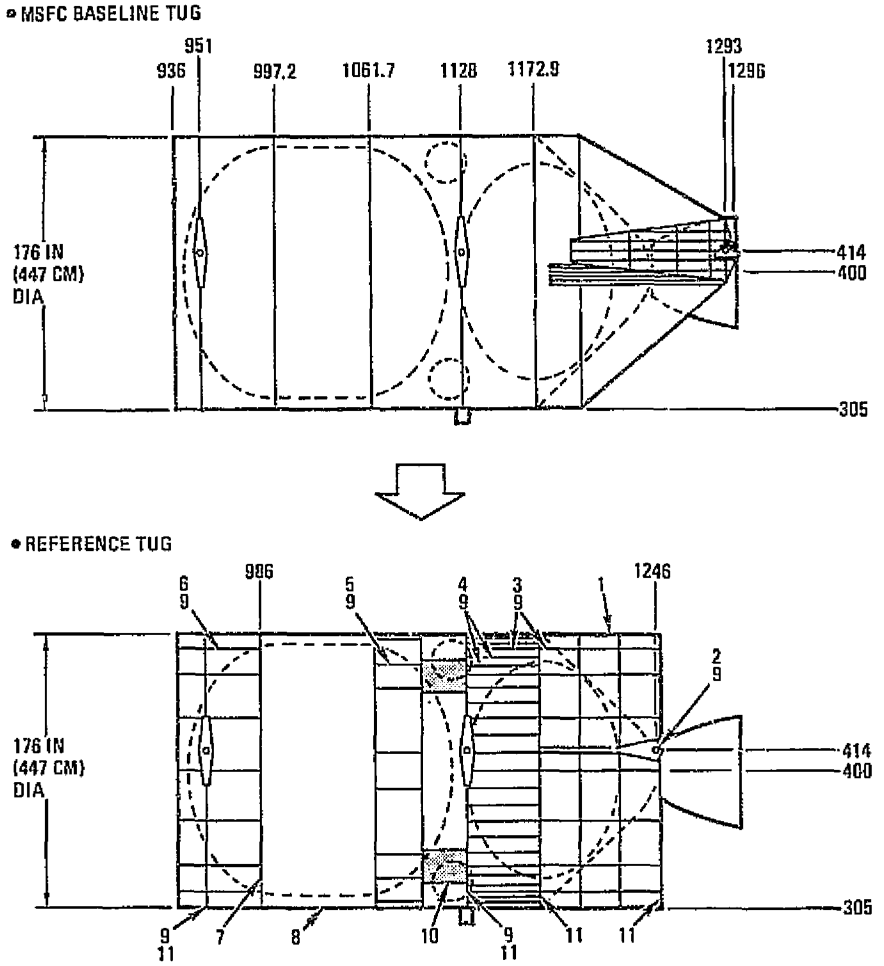
4.2.1.1 Reference Tug. The reference Tug vehicle structure was derived from the NASA baseline Tug defined in MSFC 68M00039-2 and shown on NASA drawing 10M23300. Overall dimensional characteristics (length, diameter, propellant tank volumes) of the Tug itself were retained but several revisions were made to the body structure. In addition the bifurcated shell deploy adapter (NASA drawing 10M13349) was replaced with a cylindrical shell similar to that developed during the Convair STSS. Figure 4.2-4 shows the NASA baseline and updated study reference Tugs and identifies the differences. Figures 4.2-5 and 4.2-6 further define the basic sandwich sidewall and solid laminate panels incorporated in the reference configuration body structure to simplify longeron attachment and to aid load introduction and distribution into the thin sidewall facings. To decrease weight yet provide increased stiffness the all-composite major frame concept shown in Figure 4.2-7 was adopted.

The reference Tug shell configuration shown in Figure 4.2-4 was used for structural arrangements employing the baseline rotational deploy concept with support adapter. In structural arrangements employing the rotation-aid and non-rotational deploy concepts, the load-carrying support adapter was deleted; consequently all interface fittings had to be located on the Tug flight vehicle body. But the aft end of the reference Tug was located at X_o 1172.9 (Figure 4.2-4) and the Orbiter cargo retention point nearest and forward of that location (X_o 1128, Figure 4.2-8) had insufficient capability to withstand the anticipated maximum longitudinal support reactions during the ascent phase ($+X_{MAX} > 100$ k lb, whereas, per Table 4.2-1, X_o 1128 +X capability is 68 k lb).

However, the next X-retention point aft of X_o 1172.9 (X_o 1187, Figure 4.2-8) provides +X capability of 120 k lb (54×10^3 kg) (Table 4.2-1 and Figure 4.2-9). Consequently the Tug body shell was extended from X_o 1172.9 to X_o 1187 to accommodate Tug/Orbiter interface fittings at that location for structural arrangements employing rotation aid and non-rotational deploy concepts. Figure 4.[illegible]A illustrates the reference Tug configuration for deploy concepts without a load carrying support adapter.

4.2.1.2 Baseline Orbiter. The Shuttle Orbiter description and payload accommodations specified in JSC 07700, Vol XIV, Rev C, were used to define the coordinate system, the cargo bay envelope, and the locations of structural support provisions, which are summarized in Figure 4.2-8, and to define limit support reaction capabilities, which are summarized in Table 4.2-1 and Figure 4.2-9. Where noticeable allowable support reaction capability discrepancies existed within this document, the lesser value was used as shown by the circled values in Table 4.2-1.

Late in the study, preliminary Orbiter mid-fuselage design load and relative deflection data was received. This data is presented and used in the redundant support analysis (Section 4.2.3.9).



REVISION SUMMARY

ITEM	DESCRIPTION	BASIS
1	REPLACE BIFURCATED ADAPTER WITH CYLINDRICAL ADAPTER	LIGHTER; HIGHER ±Y STIFFNESS
2	RELOCATE X-SUPPORT/PIVOT	ORBITER HAS SUPPORTS AT $X_0$1246, 1303 ONLY; ENGINE VIOLATES ENVELOPE USING $X_0$1303 PIVOT
3	ADD LATCH LONGERONS TO TUG & ADAPTER	
4	ADD OXIDIZER TANK SUPPORT LONGERONS TO TUG	INTRODUCE CONCENTRATED LOADS TO SHELL
5	ADD FUEL TANK SUPPORT LONGERONS TO TUG	
6	ADD SPACECRAFT SUPPORT LONGERONS TO TUG	
7	REPLACE FUEL TANK FWD SUPPORT ROLLERS WITH TANGENTIAL STRUTS; REVISE/RELOCATE LOAD RING	LIGHTER; STIFFER; CONTINUALLY LOAD – CARRYING
8	REVISE BASIC SANDWICH SIDEWALL	CONVAIR IRAD POINT DESIGN (FIGURE 4.2-5)
9	PROVIDE SOLID LAMINATE "PANS" IN SIDEWALL AT LONGERONS & INTERFACE FRAMES, FITTINGS	SIMPLIFY ATTACHMENT; DISTRIBUTE LOADS INTO SIDEWALL (FIGURE 4.2-6)
10	CLOCK ACPS ARRAY 45 DEG	AVOID IMPINGEMENT ON $X_0$1128 FITTINGS
11	REPLACE MAJOR FRAMES WITH ALL – COMPOSITES CONCEPT	LIGHTER;STIFFER (FIGURE 4.2-7)

Figure 4.2-4. Update of MSFC Baseline Tug to Study Reference Configuration

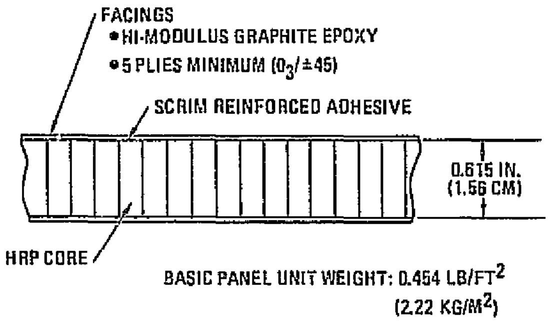


Figure 4. 2-5. Basic Sandwich Sidewall

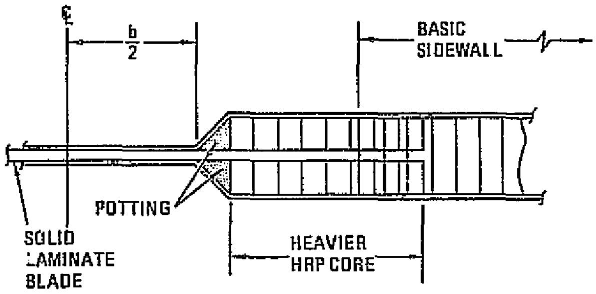


Figure 4. 2-6. Solid Laminate Pan Concept

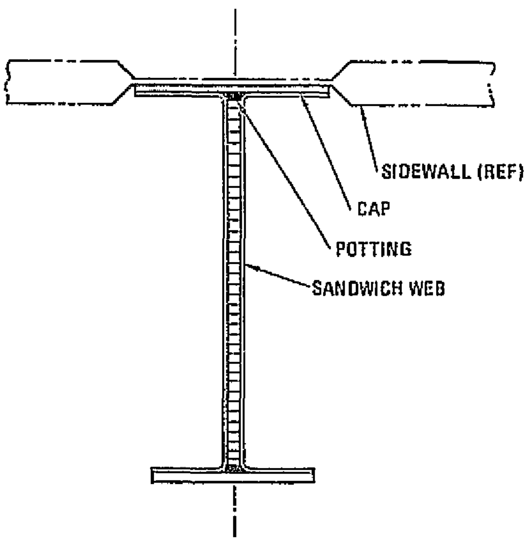


Figure 4. 2-7. Major Frame Concept

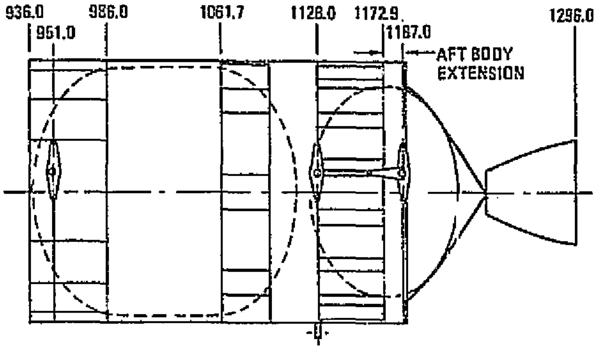


Figure 4. 2-7A. Reference Tug for Deploy Concepts Without Support Adapter

4. 2. 1. 3 Orbiter Cargo Bay Accelerations. In the course of the study, three distinct sets of Orbiter cargo-bay accelerations were specified for use in support reaction analysis. These are presented in Table 4. 2-2 in the same sequence in which they were used. Sections 4. 2. 2. 2 and 4. 2. 3. 8 discuss each set and provide and compare the results of the analyses using them.

4. 2. 1. 4 Reference Spacecraft. A deployment spacecraft weighing 11, 000 pounds (4990 kg) with its center of gravity 145 in. (368 cm) forward of the Tug interface was selected as the reference configuration for all support reaction and body loads

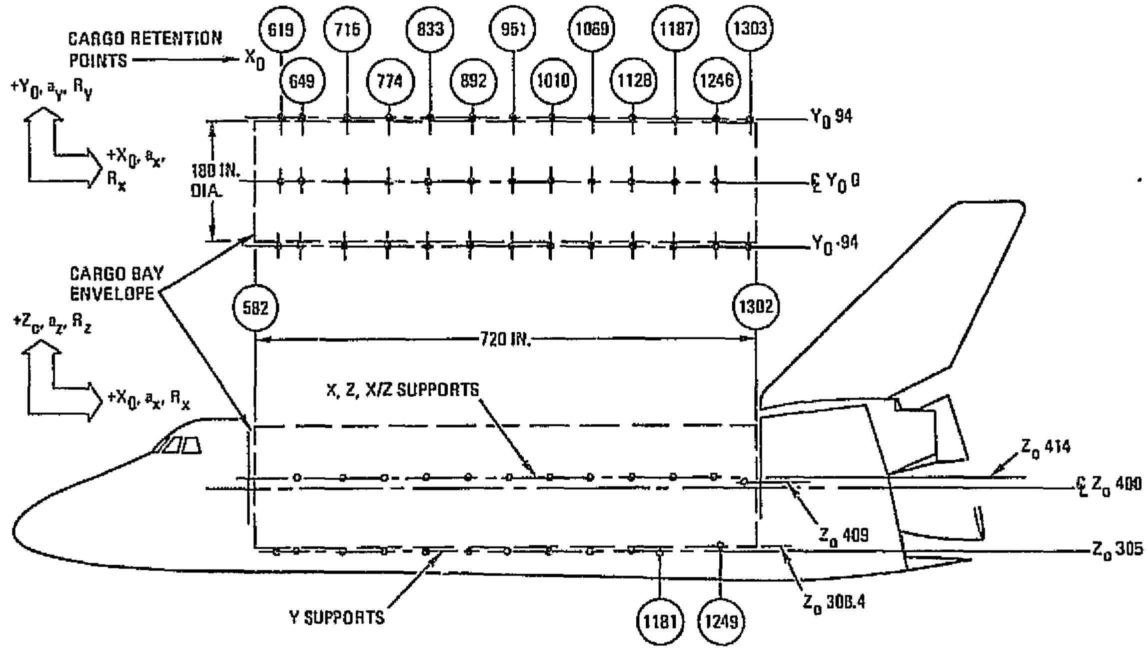


Figure 4.2-8. Baseline Orbiter Coordinates, Cargo Envelope, and Cargo Retention Locations

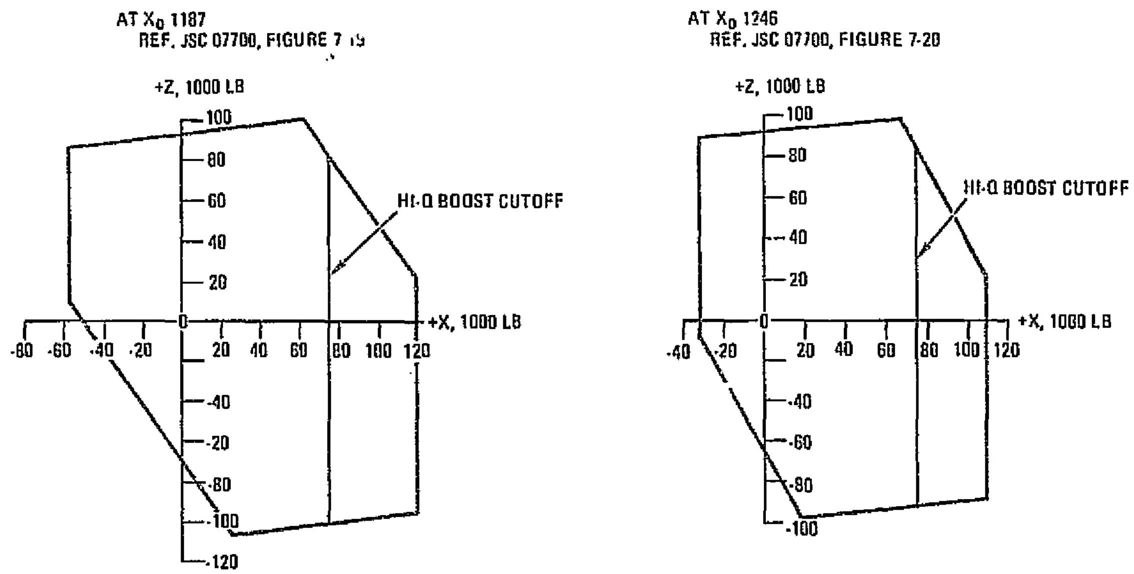


Figure 4.2-9. Orbiter Limit Support Reaction Capability Envelopes for X, Z Interaction

Table 4.2-1. Orbiter Individual Limit Support Reaction Capabilities

Support Reaction	Ref JSC 07700 Figure	Reaction Capability at Cargo Retention Locations (10^3 lb)													
		951		1010		1069		1128		1187/1181		1246/1249		1303	
		HI-Q	Other	HI-Q	Other	HI-Q	Other	HI-Q	Other	HI-Q	Other	HI-Q	Other	HI-Q	Other
+X only	7-7 7-15 thru -20	36 36	54 54	42 43	56 56	52 52	69 70	56 56	68 68	76/ 76/	120/ 120/	76/ 75/	111/ 110/	76 ?	113 ?
	Use	36	54	42	56	52	69	56	68	76/	120/	75/	110/	76	113
-X only	7-7 7-15 thru -20	? 20	? 20	? 20	? 20	? 27	? 27	? 25	? 25	? 50/	? 50/	? 32/	? 32/	? ?	? ?
	Use	20	20	20	20	27	27	25	25	50/	50/	32/	32/	?	?
+ (-) Y	7-8	—	70	—	80	—	78	—	72	—	/67	—	/56	—	—
	Use	70	70	80	80	78	78	72	72	/67	/67	/56	/56	—	—
+Z only	7-9 7-15 thru -20	? 52	67 52	? 58	65 58	? 57	72 57	? 51	71 51	? 93/	107/ 93/	? 92/	97/ 92/	? ?	67 ?
	Use	52	52	58	58	57	57	51	51	93/	93/	92/	92/	67	67
-Z only	7-9 7-15 thru -20	? 68	67 68	? 61	65 61	? 68	72 68	? 65	71 65	? 70/	107/ 70/	? 65/	97/ 65/	? ?	67 ?
	Use	67	67	61	61	68	68	65	65	70/	70/	65/	65/	67	67

= Lesser value used in cases of noticeable discrepancy within JSC 07700.

Mission Phase	Load Condition	MSFC 68M00039-1[4] [7]								
		ax		ay		az		ax		
		Max	Min	Max	Min	Max	Min	Max	Min	M
Ascent[1]	Liftoff							-0.1	-2.9	+1
	Thrust buildup/rebound	-0.5	-1.5	+0.3	-0.3	+0.3	-0.3			
	Launch release	+0.4	-3.4	+0.8	-0.8	+3.0	-3.0			
	Tug only									
	Spacecraft only									
	HI-Q boost	-1.7	-2.3	+0.9	-0.9	+1.1	-1.1	-1.6	-2.0	+0
	Max g with SRM	-2.7	-3.3	+0.5	-0.5	+0.6	-0.6	-2.7	-3.3	+0
	SRM cutoff/separation	+2.0	-4.0	+0.4	-0.4	+0.8	-0.8			
	Max g, orbiter only	-2.7	-3.3	+0.3	-0.3	-0.4	-0.8	-2.7	-3.3	+0
	Orbiter cutoff/separation	+1.9	-2.1	+0.4	-0.4	+0.6	-0.2			
On-orbit[1]	Payload deployment	+0.2	-0.2	+0.2	-0.2	+0.2	-0.2			
Descent[1]	Entry and	+1.4	+0.6	+0.7	-0.7	+4.0	+2.0			
	Flyback	+0.6	-0.6	+0.3	-0.3	+1.4	+0.6			
	+ Pitch maneuvers							+1.06	-0.02	0
	- Pitch maneuvers							+1.06	-0.02	0
	± Yaw maneuvers							+0.75	+0.75	+1.
	± Roll maneuvers									
	Landing	+1.3	+0.7	+0.3	-0.3	+3.0	+1.0	+1.0	-0.8	+0.
	Tug only									
	Spacecraft only									
Crash[2]	Longitudinal (± X)[3]	+9.0	-1.5	0	0	0	0	+9.0	-1.5	0
	Lateral (± Y)	0	0	+1.5	-1.5	0	0	0	0	+1.
	Vertical (± Z)	0	0	0	0	+4.5	-2.0	0	0	0

Notes: (1) Ascent, on orbit, and descent accelerations are limit values.

(2) Crash accelerations are ultimate. Resulting loads shall be applied to the Tug/Orbiter support fittings and their attachment fasteners only. Supporting structure shall be designed to withstand the fastener loads locally.

(3) The longitudinal (± X) crash accelerations may occur in any direction within a cone of 20 degrees (semi-vertex angle) about the X-axis.

FOLDOUT FRAME

7)		JSC 07700, Vol. XIV, Rev. C(5) (7)														
az		ax		ay		az		αx		αy		αz		ax		ay
x	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
		-0.1	-2.9	+1.0	-1.0	+1.5	-1.5	+0.10	-0.10	+0.15	-0.15	+0.15	-0.15	-0.3	-2.9	+0.7
3	-0.3															
0	-3.0															
														-0.3	-2.9	+0.8
														-0.3	-2.9	+1.0
.1	-1.1	-1.6	-2.0	+0.5	-0.5	+0.6	-0.6	+0.10	-0.10	+0.15	-0.15	+0.15	-0.15	-1.6	-2.0	+0.5
.6	-0.6	-2.7	-3.3	+0.2	-0.2	-0.3	-0.3	+0.20	-0.20	+0.25	-0.25	+0.25	-0.25	-2.85	-3.15	+0.2
.8	-0.8															
.4	-0.8	-2.7	-3.3	+0.2	-0.2	-0.75	-0.75	+0.20	-0.20	+0.25	-0.25	+0.25	-0.25	-2.85	-3.15	+0.2
.6	-0.2															
.2	-0.2															
.0	+2.0															
.4	+0.6															
		+1.06	-0.02	0	0	+2.5	+2.5	+0.25	-0.25	+0.75	-0.75	+0.30	-0.30	+1.1	+1.1	0
		+1.06	-0.02	0	0	-1.0	-1.0	+0.25	-0.25	+0.75	-0.75	+0.30	-0.30	+0.6	+0.6	0
		+0.75	+0.75	+1.25	-1.25	+1.0	+1.0	+0.25	-0.25	+0.30	-0.30	+0.75	-0.75	+1.0	+1.0	+1.25
														+0.9	+0.9	+0.2
.0	+1.0	+1.0	-0.8	+0.5	-0.5	+2.8	+2.2	+0.25	-0.25	+1.25	-0.75	+0.30	-0.30	+1.1	-1.5	+0.7
														+1.1	-1.5	+0.8
														+1.1	-1.5	+1.4
)	0	+9.0	-1.5	0	0	0	0	0	0	0	0	0	0	+9.0	-1.5	0
)	0	0	0	+1.5	-1.5	0	0	0	0	0	0	0	0	0	0	+1.5
4.5	-2.0	0	0	0	0	+4.5	-2.0	0	0	0	0	0	0	0	0	0

ed to the Tug/Orbiter
structure shall be

tion within a cone of

(4) MSFC 68M00039-1 accelerations include Orbiter dynamic transient and cargo dynamic response effects.

(5) JSC 07700 ascent and landing accelerations include Orbiter dynamic transient effects but do not include cargo dynamic response effects.

(6) MSFC PF02-75-31 accelerations apparently include Orbiter dynamic transient and cargo dynamic respon

(7) Linear accelerations are in g; angular accelerations are in radians/sec^2.

FOLDOUT FRAME 2

Table 4.2-2. Orbiter Cargo Bay Accelerations

	MSFC PF 02-75-31(6) (7)											
	ax		ay		az		αx		αy		αz	
Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
.15	-0.3	-2.9	+0.7	-0.7	+0.9	-1.1	+0.15	-0.15	+0.10	-0.10	+0.10	-0.10
	-0.3	-2.9	+0.8	-0.8	+0.9	-1.1	+0.15	-0.15	+0.10	-0.10	+0.10	-0.10
	-0.3	-2.9	+1.0	-1.0	+1.4	-1.6	+0.15	-0.15	+0.15	-0.15	+0.15	-0.15
.15	-1.6	-2.0	+0.5	-0.5	+0.6	-0.6	+0.15	-0.15	+0.10	-0.10	+0.10	-0.10
0.25	-2.85	-3.15	+0.2	-0.2	+0.3	-0.3	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10
0.25	-2.85	-3.15	+0.2	-0.2	-0.75	-0.75	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10
0.30	+1.1	+1.1	0	0	+2.5	+2.5	0	0	-0.1	-0.1	0	0
0.30	+0.6	+0.6	0	0	-1.0	-1.0	0	0	+0.7	+0.7	0	0
0.75	+1.0	+1.0	+1.25	-1.25	+1.0	+1.0	0	0	0	0	+0.2	-0.2
	+0.9	+0.9	+0.2	-0.2	+1.5	+1.5	+2.6	-2.6	+0.3	+0.3	+0.2	-0.2
0.30	+1.1	-1.5	+0.7	-0.7	+3.3	+0.7	+0.2	-0.2	+0.2	-0.2	+0.1	-0.1
	+1.1	-1.5	+0.8	-0.8	+4.0	0	+0.2	-0.2	+0.2	-0.2	+0.1	-0.1
	+1.1	-1.5	+1.4	-1.4	+7.0	-3.0	+0.2	-0.2	+0.4	-0.4	+0.2	-0.2
0	+9.0	-1.5	0	0	0	0	0	0	0	0	0	0
0	0	0	+1.5	-1.5	0	0	0	0	0	0	0	0
0	0	0	0	0	+4.5	-2.0	0	0	0	0	0	0

argo dynamic response effects.

sient effects but do not include

FOLDOUT FRAME 3

isient and cargo dynamic response effects.

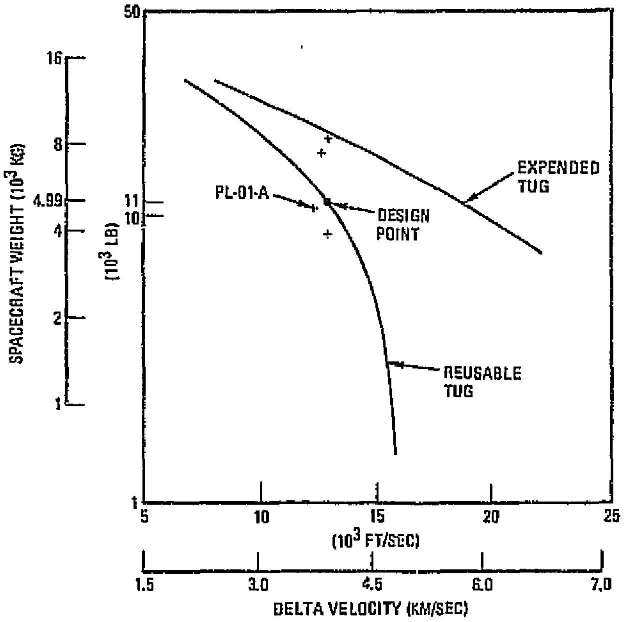


Figure 4.2-10. MSFC Baseline Tug Performance

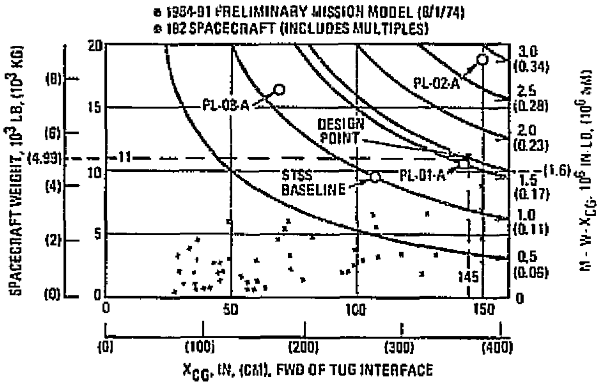


Figure 4.2-11. Spacecraft Weight/CG Distribution

analyses. The selection process is illustrated in Figures 4.2-10, 4.2-11, and 4.2-12 and is based on the following rationale:

a. Tugs flown in an expendable mode can, if necessary, be modified for their final flight (i.e., can incorporate mission peculiar structural reenforcement if required).

b. Conversely, reusable Tugs are structurally standardized (i.e., are designed for a single set of conditions which, presumably, envelope all spacecraft within the Tug reusable-mode performance capability).

c. From Figure 4.2-10 the heaviest S/C in the 1984-91 preliminary mission model that can be deployed in a reusable-Tug mode is PL-01-A, which weighs 10571 lb (4795 kg). From Figure 4.2-11, the 1 g moment it produces at the Tug/spacecraft interface is approximately 1.5×10^6 in-lb. (1.7×10^5 Nm).

d. Insufficient kick stage length exists for moving most heavier spacecraft into a reusable Tug's capability range.

e. From Figure 4.2-10 and 4.2-11 an 11k lb (5×10^3 kg) S/C lying on the performance boundary and having a 145 in. (368 cm) arm to its cg produces 1.6×10^6 in-lb (1.8×10^5 Nm) interface moment, which envelops virtually all of the mission model. This is further illustrated in Figure 4.2-12 in which this S/C is located on weight and moment histograms. Only four of the 182 identified flights (two flights each of two future spacecraft designs) lie beyond the design point. Options for support of these spacecraft are discussed in Section 4.2.4.2.

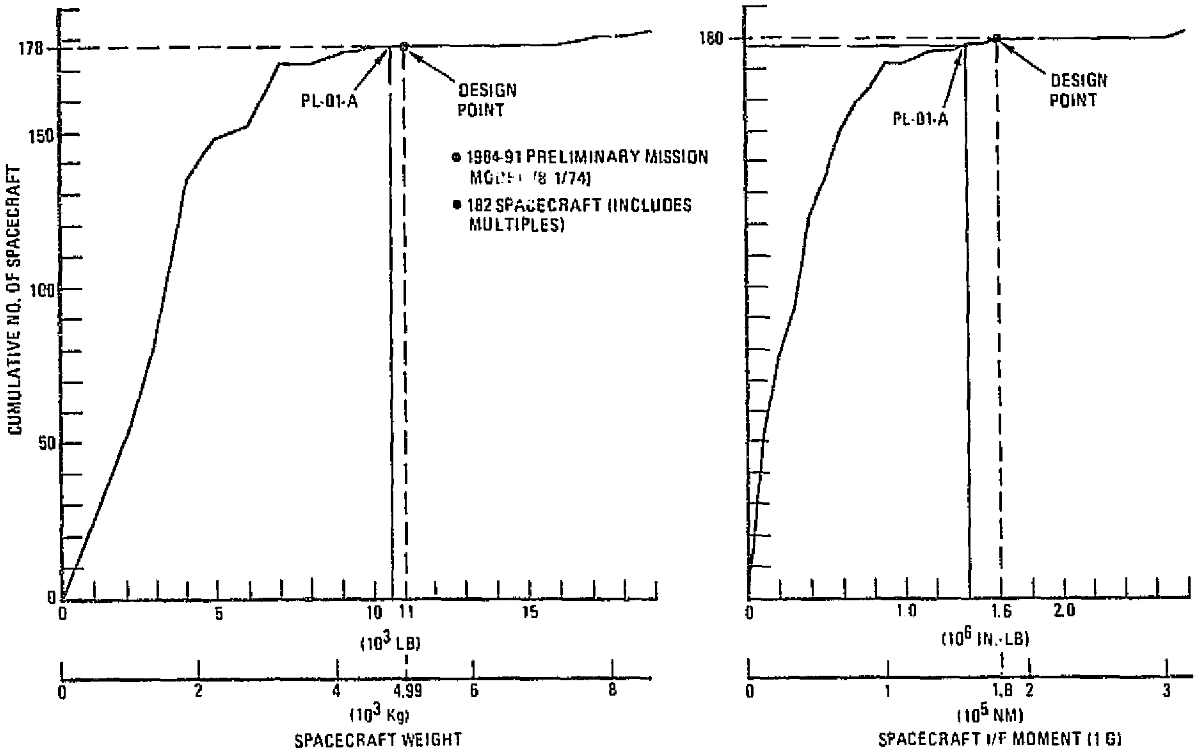


Figure 4.2-12. Spacecraft Weight, Moment Histograms

4.2.1.5 <u>Mass Properties</u>. Weight, center of gravity, and (later in the study) mass moment of inertia data were developed for those elements suspended from the primary Tug/Orbiter structural attachments, for use in the initial support reaction and weight/performance (Sections 4.2.2.2 and 4.2.2.3) evaluations and in subsequent updates (Sections 4.2.3.8 and 4.2.3.10). The data presented in this Section was compiled and was used as input to those tasks noted above and does not reflect the implied new Tug baseline configuration resulting from incorporation of the subsystem changes recommended in this study. Sufficient data was initially developed to permit definition of all possible mass configurations considering both vehicle deployment concepts (with and without adapter), both mission types (deployment of the reference spacecraft and retrieval of the heaviest retrievable spacecraft), and all mission phases (ascent, nominal descent, abort descent, and crash). The number of mission type and phase combinations actually investigated was subsequently limited to those corresponding to the critical load conditions identified in Section 4.2.2.2.

Specific ground rules and assumptions used in developing mass properties included:

a. Tug length (station location of forward interface, X_0 936) and tank volumes were held constant in all support arrangement candidates (i.e., no length or propellant volume variation to offset performance Δs between candidates).

b. Propellants were loaded to the maximum permissible level (i.e., either to tank capacity for the retrieval mission, or to a quantity resulting in 65,000-lb (29510 kg) total mission chargeable weight in the Orbiter for the deployment mission).

c. Oxidizer was dumped during abort (i.e., the oxidizer tank was empty during abort descent and crash mission phases).

d. Initially, fuel was not dumped during abort (i.e., the fuel tank was full during abort descent and crash mission phases). Data generated in tasks 4.2.2.2 and 4.2.2.3 were based on this ground rule. During the study this ground rule was reversed, and fuel abort dump was adopted in the MSFC baseline Tug. Consequently, data generated thereafter in the support reaction and weight/performance update tasks (4.2.3.8 and 4.2.3.10) reflected an empty fuel tank for abort descent and crash.

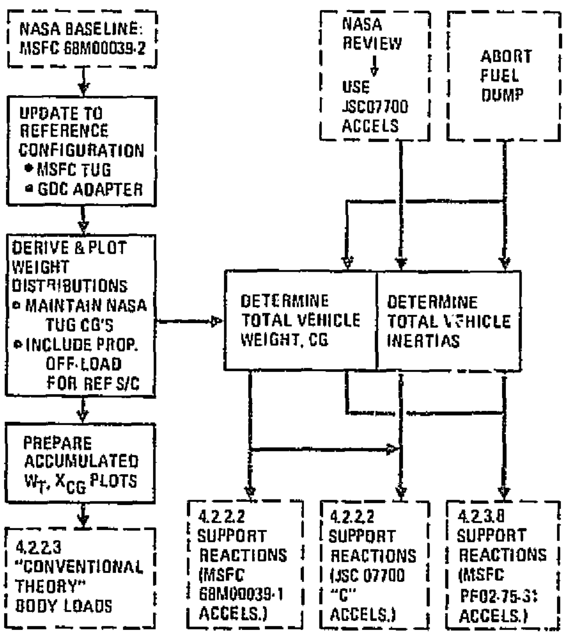


Figure 4.2-12A. Development of Mass Properties Data

Mass property data in support of the reaction and "conventional theory" loads calculations in Sections 4.2.2.2 and 4.2.2.3 was developed as shown in Figure 4.2-12A. The NASA baseline Tug weight data per MSFC 68M00039-2 was initially assumed to apply to the reference configuration despite the configuration differences discussed in Section 4.2.1.1. The weight changes associated with the baseline/reference configuration differences were not initially incorporated for two reasons: 1) the support reactions and body loads tasks required mass properties data as input but were scheduled before the various design tasks in which detailed weight data was to be developed; consequently, the baseline data was the best data available at that time, and 2) the net weight change due to the total effect of the various baseline/reference configuration differences was expected to be small enough that its resulting effect on reactions and body loads would be neglibible. Similarly, the mass property variations (e.g., support fitting quantity and/or location, sidewall reinforcement, body ΔL) between the various support arrangement candidates were also ignored in support reaction and body loads computations.

Weights of those elements that vary as a function of deployment concept or support arrangement were developed during weight/performance evaluations (Sections 4.2.2.3, 4.2.3.10) and are reported there.

To support the "conventional theory" body loads analyses in Section 4.2.2.3, it was necessary to know the weight and CG of all elements forward of certain selected stations. To provide this data, it was necessary to first derive weight distributions for the Tug, its expendables, and the support adapter. This was accomplished by further definitizing the updated configuration and assigning locations and lengths to major items within the various subsystems.

The MSFC baseline Tug mass properties tables and subsystems description, augmented by STSS data, where applicable, formed the basis for the weight and location allocations. For the Tug itself, center-of-gravity locations specified in MSFC 68M00039-2 were maintained.

Figure 4.2-12B shows the resulting weight intensity versus station "skylines" for the Tug plus adapter at burnout (i.e., less expendables). The dashed curve represents the simple distribution of weight versus shell station. Since the propellant tanks and those systems/components attached to them are supported from the body at discrete points, the effective weight versus shell station differs from the simple distribution and is shown by the solid curve.

The variation in fill level and CG versus propellant quantity is shown in Figures 4.2-12C and 4.2-12D for the fuel and oxidizer tanks respectively. Figures 4.2-12E, 4.2-12F, and 4.2-12G show the accumulated weight and CG versus body station data

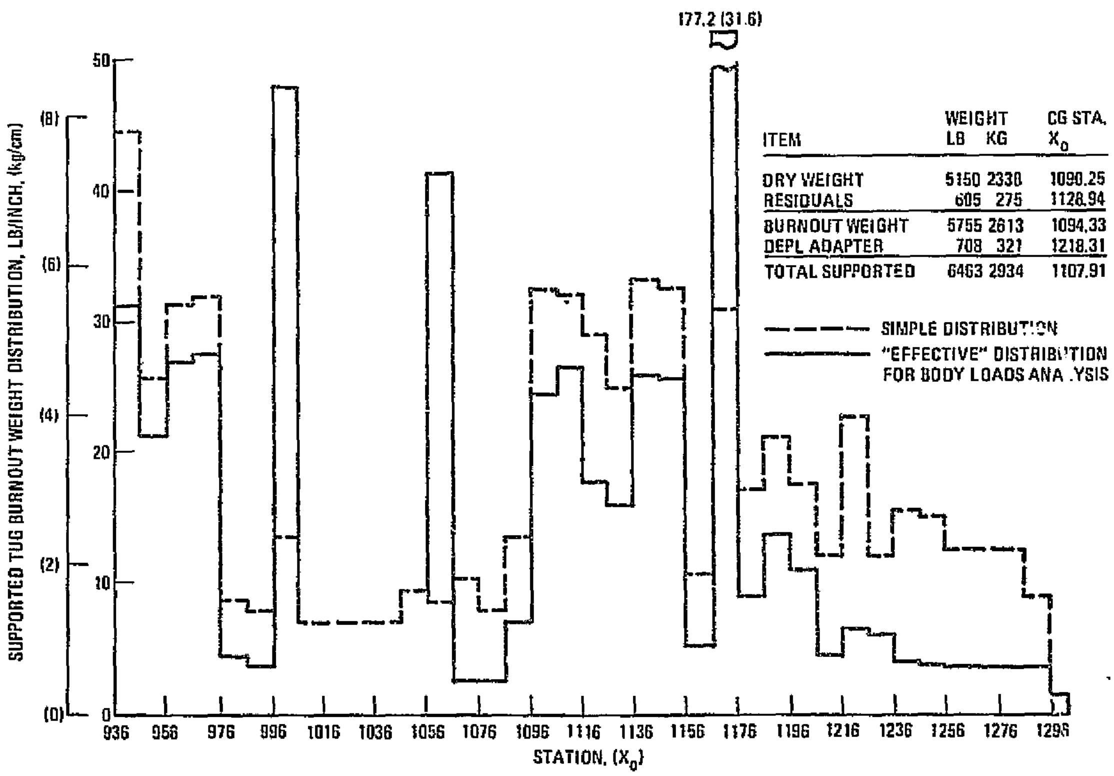


Figure 4.2-12B. Tug Plus Adapter Weight Distribution as a Function of Station Number at Burnout

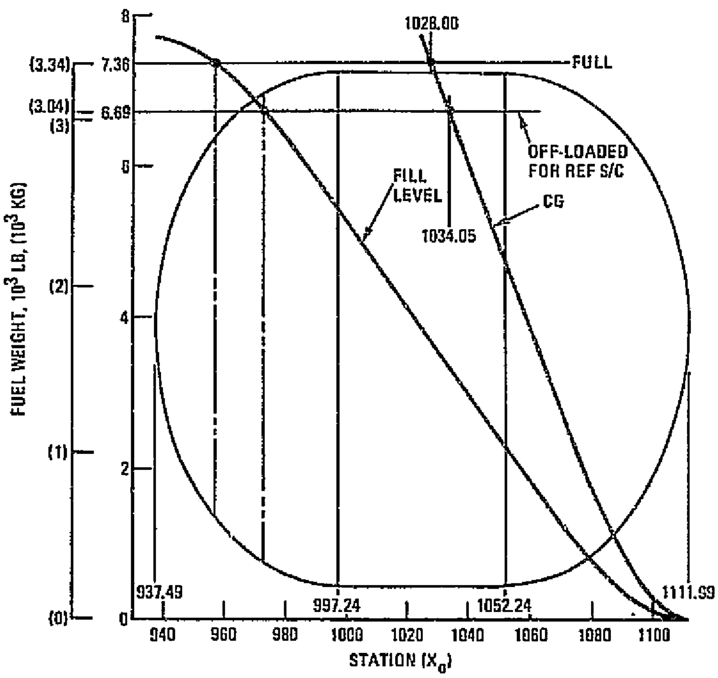


Figure 4.2-12C. Fuel Fill Level and CG versus Weight

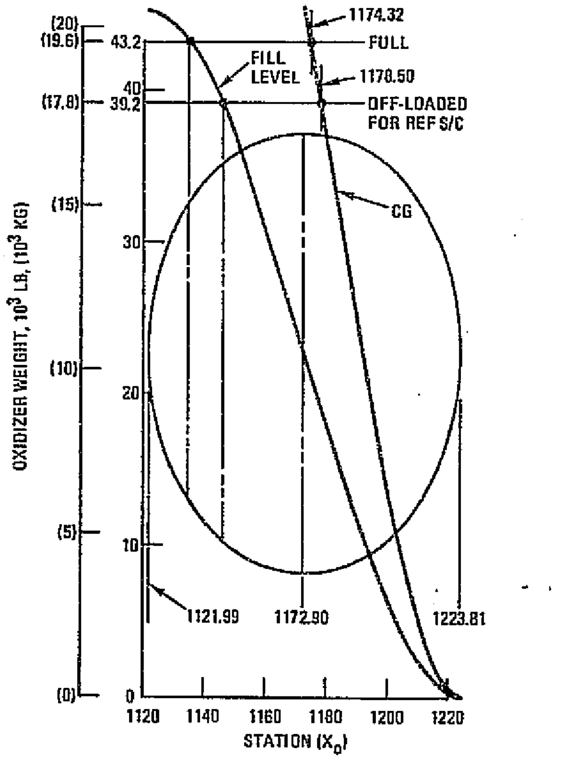


Figure 4.2-12D. Oxidizer Fill Level and CG versus Weight

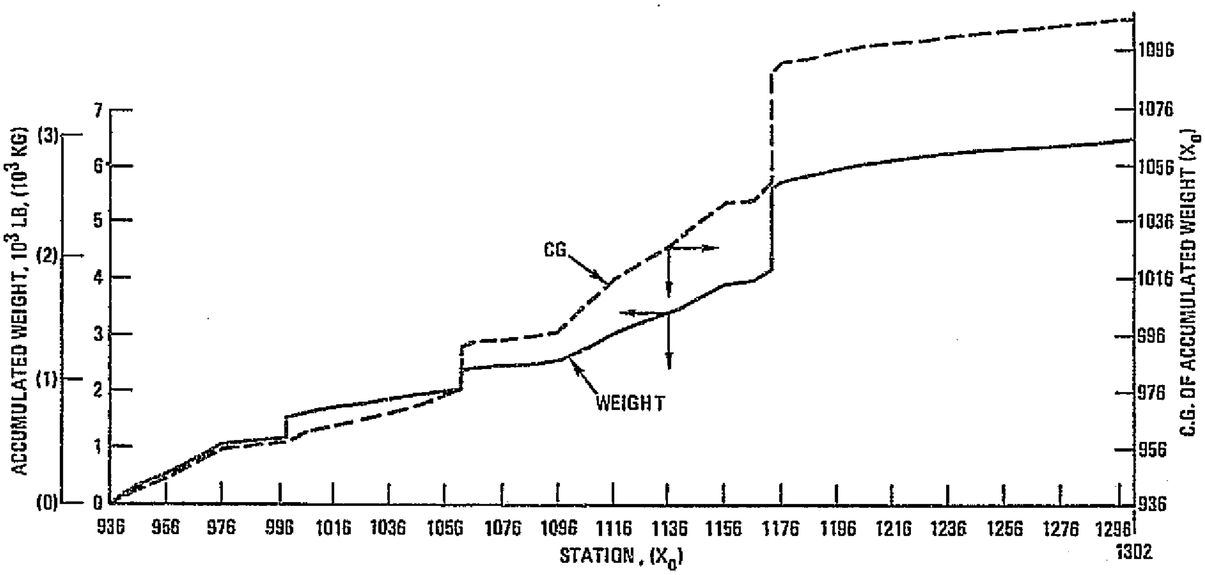
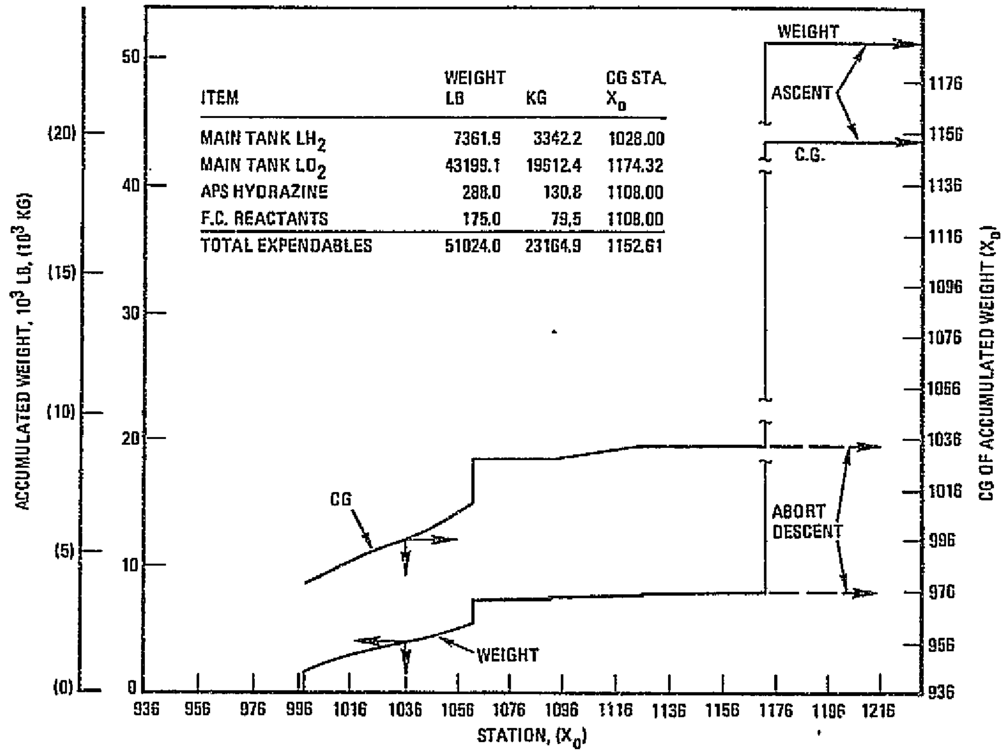


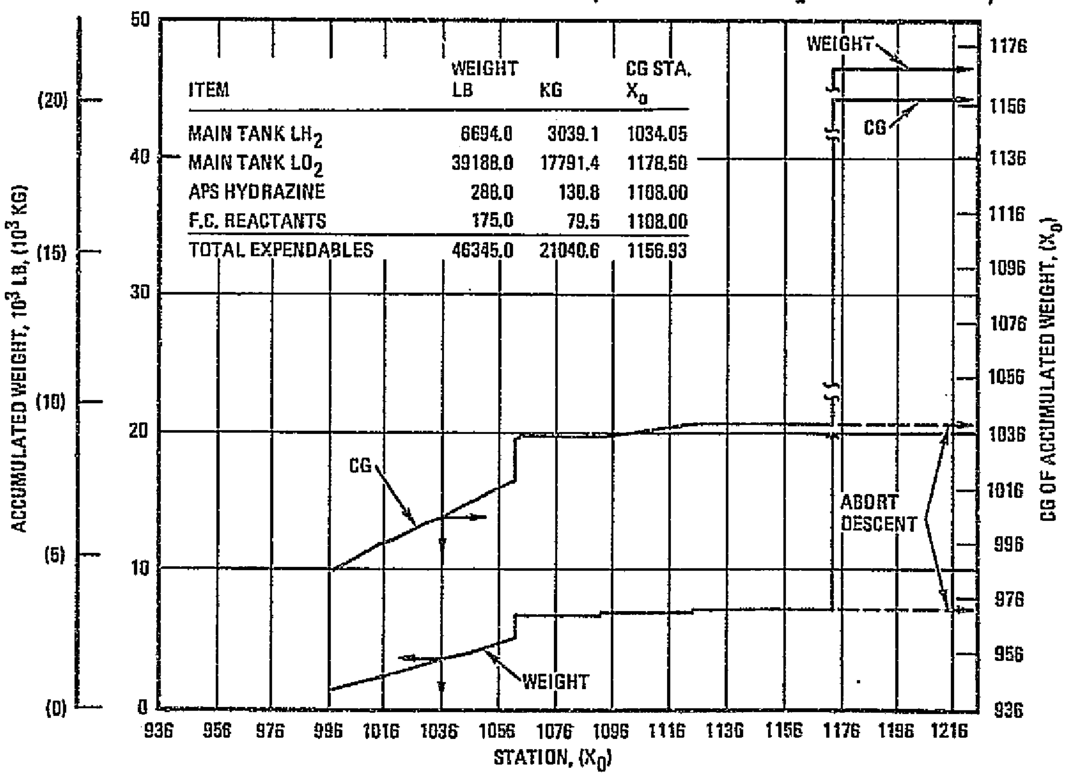
Figure 4.2-12E. Accumulated Weight, CG of Tug Plus Adapter at Burnout

C-3



ITEM	WEIGHT LB	KG	CG STA. X_0
MAIN TANK LH_2	7361.9	3342.2	1028.00
MAIN TANK LO_2	43199.1	19612.4	1174.32
APS HYDRAZINE	288.0	130.8	1108.00
F.C. REACTANTS	175.0	79.5	1108.00
TOTAL EXPENDABLES	51024.0	23164.9	1152.61

Figure 4.2-12F. Accumulated Weight, CG of Expendables for Retrieval Missions (Full Main Propellant Tanks)



ITEM	WEIGHT LB	KG	CG STA. X_0
MAIN TANK LH_2	6694.0	3039.1	1034.05
MAIN TANK LO_2	39188.0	17791.4	1178.50
APS HYDRAZINE	288.0	130.8	1108.00
F.C. REACTANTS	175.0	79.5	1108.00
TOTAL EXPENDABLES	46345.0	21040.6	1156.93

Figure 4.2-12G. Accumulated Weight, CG of Expendables for Deployment Missions (Off-Loaded Main Propellant Tanks)

derived from the preceding figures and used for conventional theory body loads computation in Section 4.2.2.3. Total vehicle weight and CG data was developed from the preceding data for each mass configuration. Figure 4.2-12H shows a typical tabulation and the resulting weight, CG schematics.

Configuration = All with Adapter
Mission = Deployment
Spacecraft = 11,000 lb (4994 kg), CG at X_o 791

Item	Weight	C.G. (X_o)	WX_o
Tug (Burnout)	5,755.0	1,094.33	6,297,869
ACPS, F.C. Fluids	463.0	1,108.00	513,00
Adapter	708.0	1,218.31	862,563
Spacecraft	11,000.0	791.00	8,701,00
Σ (Normal Descent, Crash)	17,926.0	913.45	16,374,43
+ Fuel	6,694.0	1,034.05	6,921.9
Σ(Abort Descent, Crash)	24,620.0	946.24	23,296,3
+ Oxidizer	39,188.0	1,178.50	46,183,0
Σ(Ascent)	63,808.0	1,088.88	69,479,4

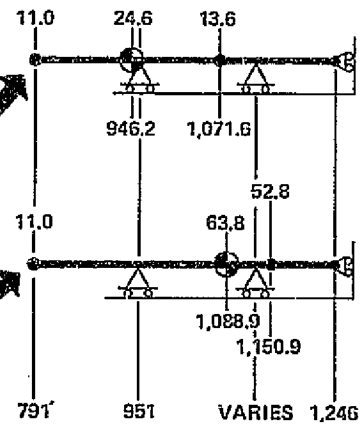


Figure 4.2-12H. Typical Weight, CG Determination

Mass moments of inertia were developed during the study to support the NASA-requested analysis of support reactions using accelerations per JSC 07700, Vol. XIV, Rev. C (which contain angular acceleration terms about all three coordinate axes). Inertia computations were based on the following ground rules and assumptions:

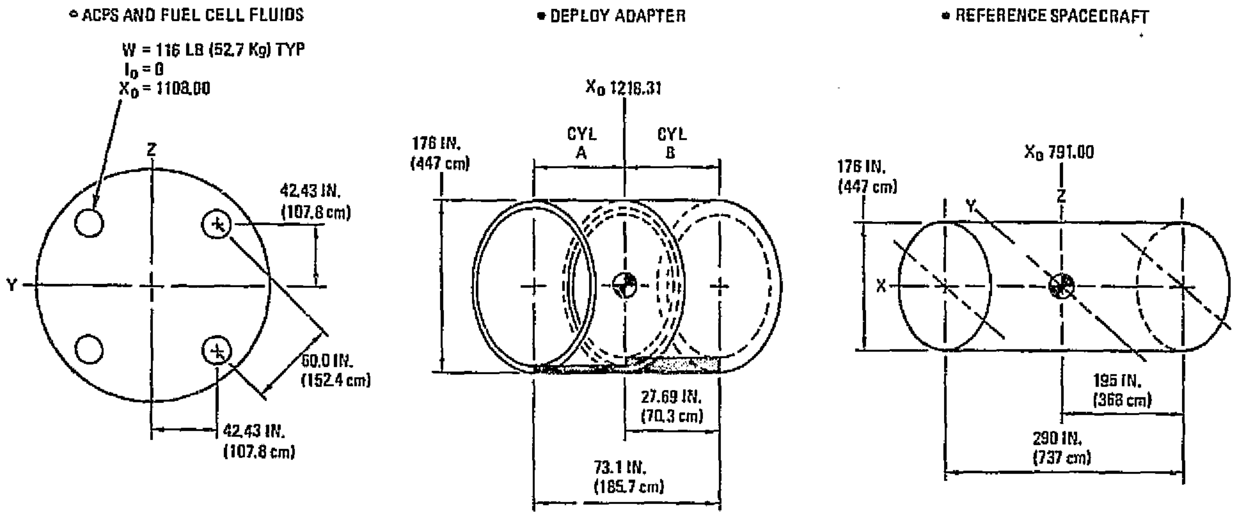
a. $I_y \equiv I_z$.

b. Tug inertia at burnout is based on the 100% main stage burn condition specified in MSFC 68M00039-2 except that $I_y \equiv I_z = 0.15191E05$ slug-ft^2.

c. ACPS and fuel cell fluids were assumed to be distributed as shown in Figure 4.2-12I.

d. The deployment adapter was assumed to consist of two adjoining thin cylinders of approximately uniform density as shown in Figure 4.2-12I.

e. The reference spacecraft was assumed to consist of a solid cylinder of uniform density as shown in Figure 4.2-12I.



INERTIA		
AXIS	SLUG-FT^2	KG-M^2
I_X	360.5	488.8
I_Y, I_Z	180.3	244.5

INERTIA		
AXIS	SLUG-FT^2	KG-M^2
I_X	1183.4	1604.7
I_Y, I_Z	655.7	889.1

INERTIA		
AXIS	SLUG-FT^2	KG-M^2
I_X	9193.1	12465.8
I_Y, I_Z	21236.0	28796.0

Figure 4.2-12I. Mass Moments of Inertia

f. Propellant roll inertia (I_x) was assumed to be zero in both tanks. Yaw and pitch inertias (I_y, I_z) were based on reduced (effective) masses derived from existing Centaur data. Resulting inertias for the retrieval (full tanks) and deployment (off-loaded tanks) missions are given in Table 4.2-3.

Table 4.2-3. Propellant Mass Moments of Inertia

Mission Type	Tank	I_y, I_z Slug-ft^2	I_y, I_z kg-m^2	CG Sta X_o
Retrieval (Full Tanks)	Fuel	4,245.2	5,756.5	1,028.00
	Oxidizer	8,696.2	11,792.0	1,174.32
Deployment (Ref S/C) (Off-loaded Tanks)	Fuel	3,567.1	4,837.0	1,034.05
	Oxidizer	7,552.2	10,240.8	1,178.50

4.2.2 SUPPORT CANDIDATE DEFINITION AND PRELIMINARY SCREENING. The support candidate definition and preliminary screening tasks were conducted in the sequence illustrated in Figure 4.2-13. Presentation of data in this section is divided into the subsections noted in the task sequence blocks.

4.2.2.1 Structural Arrangement Candidates. Support locations included in the candidate evaluation analysis were limited to those compatible with both the baseline Orbiter provisions and the reference Tug configuration. Primary Orbiter structural attachment locations on the payload bay longerons and keel were obtained from JSC 07700, Vol XIV, Rev C, (reference Figure 4.2-8). Tug geometry considerations were used to further screen potential support fitting locations. All Orbiter identified support stations between X_o 951 and 1249, except X_o 1010 and 1069, were found to be acceptable. Stations 1010 and 1069 are located adjacent to the Tug hydrogen tank, which allows insufficient space for moment carrying Tug support frames. Figure 4.2-14 illustrates candidate Orbiter support stations and defines the support reaction designations used in all analyses. (Note that support designations do not agree with those on MSFC drawing 10M23300 since the selection and preliminary analysis of candidate support concepts was in work before receipt of the drawing.) X-supports were limited to X_o 1187 and 1246 due to insufficient Orbiter capability at X_o 1128 and forward. Y- and Z- supports were permitted at all appropriate locations. The illustrated support arrangement is that of the MSFC baseline Tug, except for (Y2) and (Z4), which represent support locations used in some arrangements in addition to the minimum required for statically determinate configurations. For the screening analyses, 21 candidate Tug/Orbiter structural support arrangements were generated. These were divided into three categories:

a. Statically determine systems.

b. Singly redundant (or load-balanced) systems.

c. Doubly redundant (or load-balanced) systems.

Within each category, similar support arrangement candidates were collected into families. The -1 and -3 options in each configuration family placed the aftmost supports at X_o 1246 on a support adapter for compatibility with the baseline Tug support/rotational deployment concept. The -2 option in each family placed the aftmost supports at X_o 1187 on an extension of the reference Tug flight vehicle body for compatibility with the rotation aid and non-rotational support/deployment concepts. The detail description of each candidate is presented in Figures 4.2-15A, B, and C.

Statically Determinate Systems. The three statically determinate configuration families were similar in that each employed a total of six supports: two X, one Y, and three Z. In Family 1 the six supports were provided using only four Tug/Orbiter interface points by combining two Z supports with the two X supports at the aft end of

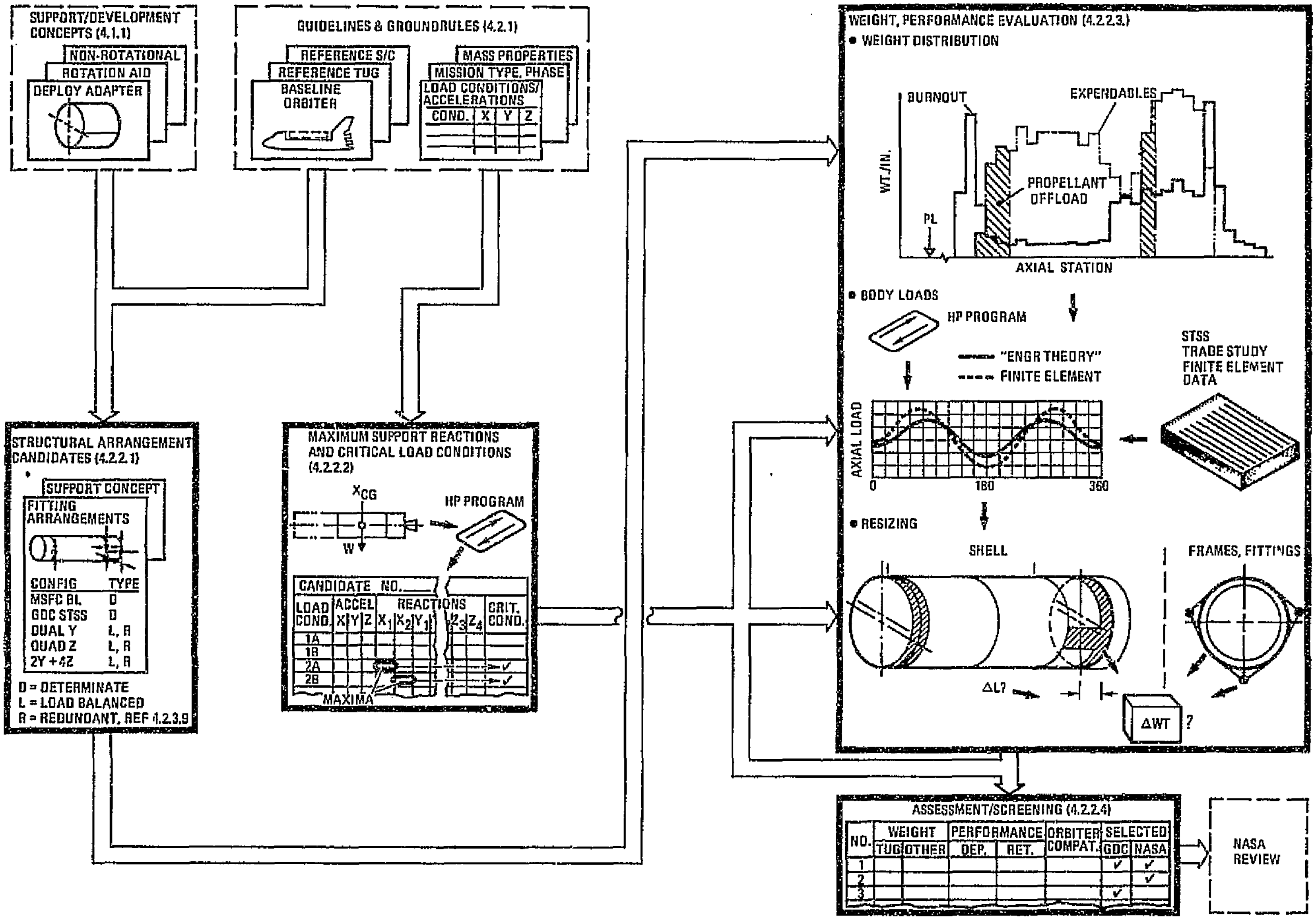


Figure 4.2-13. Task Sequence and Corresponding Report Sections

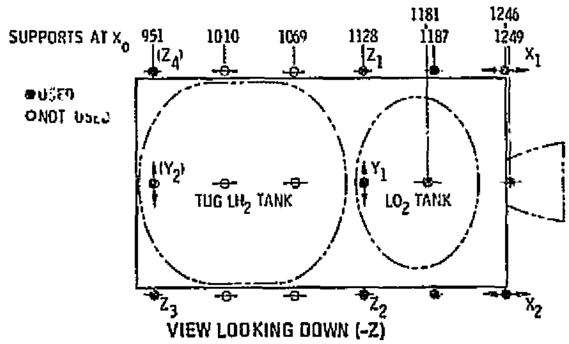


Figure 4.2-14. Candidate Support Locations and Support Reaction Designations

the vehicle. The third Z support was then located on one side of the vehicle near the forward end. It is the preferred cargo retention system shown in JSC 07700, Vol. XIV. It was also selected from among those arrangements investigated earlier in the GDC STSS as the recommended system at that time. Family 6 was a six-point system that provided two Z supports and the single Y support in a common plane at an intermediate station within the vehicle CG excursion band. It was the arrangement used for the NASA baseline Tug as presented in MSFC drawing 10M23300. Family 7 was a five-point system providing two Z supports plus the single Y support in a common plane near the forward end of the vehicle. The third Z support was then combined with one of the two aft X supports. It was one of the arrangements investigated earlier in the GDC STSS and was found to provide performance similar to the recommended Family 1 system and was designated as an alternative system at that time.

Redundant/Load Balanced Systems. These systems incorporated supports in addition to the minimum number required in the statically determinate systems. Families 2, 3, and 8 each added one additional support (a fourth Z in 2 and 8 and a second Y in 3). Families 4 and 5 each added both a fourth Z and a second Y support. Normally the evaluation of these systems would have required an elastic analysis to account for the effects of the redundant support(s). However, Orbiter stiffness and relative deflection data were not available upon study commencement. Furthermore, it was not at all clear in advance that redundant attachment would result in tolerable support reactions. Nevertheless, the quad-Z and dual-Y systems offered potential reaction, deflection, and dynamic response benefits. Consequently various hydralic load-balancing systems, (based on a concept presented by MDAC in the SOAR study) were developed, which precluded indeterminacy by eliminating antisymmetric support reaction components at specified locations. For example, Family 2 is essentially Family 1 with a fourth Z support. Balancing the forward Z supports consists of floating the supports on hydraulic cylinders, which permits the two supports to share the reaction previously carried by the single forward Z alone (in Family 1), but prevents antisymmetric Orbiter relative twist from inducing additional reactions.

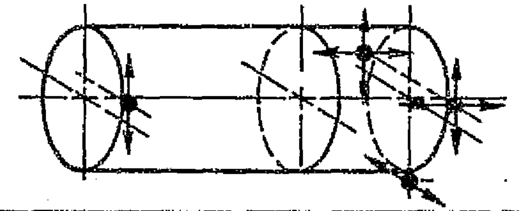
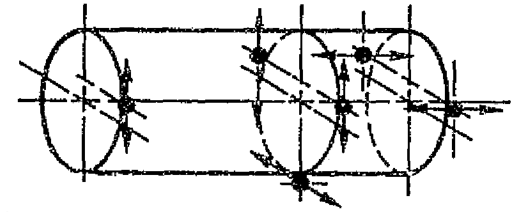
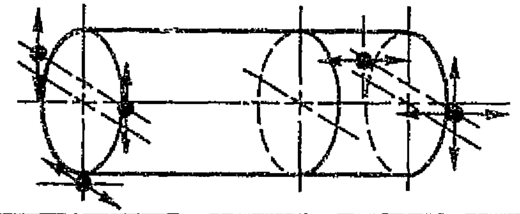
CONFIGURATION					SUPPORT LOCATIONS						
NO.	DESCRIPTION	ARRANGEMENT	OPTION	ADAPTER?	X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
1	GDC STSS PREFERRED		-1 -2	YES NO	1246 1187	1249 1181	– –	1246 1187	1246 1187	951 951	– –
6	MSFC BASELINE		-1 -2	YES NO	1246 1187	1128 1128	– –	1128 1128	1128 1128	951 951	– –
7	GDC STSS ALTERNATIVE		-1 -2	YES NO	1246 1187	951 951	– –	951 951	951 951	1246 1187	– –

Figure 4.2-15A. Statically Determinate Support Arrangements

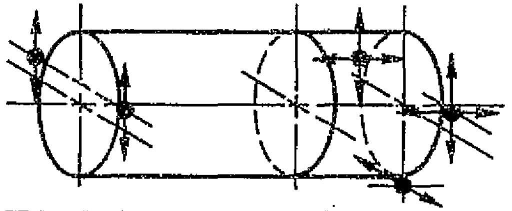
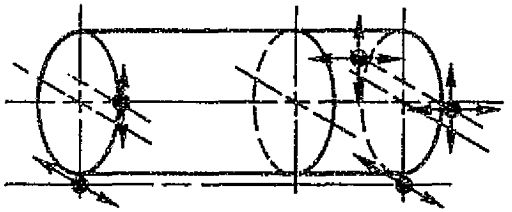
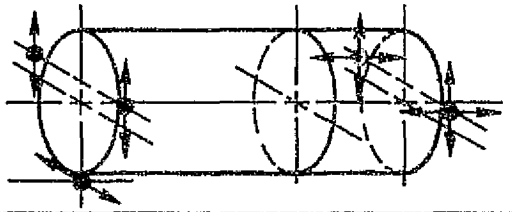
CONFIGURATION					SUPPORT LOCATIONS						
NO.	DESCRIPTION	ARRANGEMENT	OPTION	ADAPTER?	X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
2	DUAL FWD Z + AFT Y FWD Z BALANCED		-1 -2 -3	YES NO YES	1246 1187 1246	1249 1181 1128	– – –	1246 1187 1128	1246 1187 1128	951 951 951	951 951 951
3	DUAL Y X BALANCED		-1 -2 -3	YES NO YES	1246 1187 1246	1249 1181 1128	951 951 951	1246 1187 1128	1246 1187 1128	951 951 951	– – –
8	DUAL FWD Z + FWD Y AFT Z BALANCED		-1 -2 -3	YES NO YES	1246 1187 1246	951 951 951	– – –	951 951 951	951 951 951	1246 1187 1128	1246 1187 1128

Figure 4.2-15B. Singly Redundant Load Balanced Support Arrangements

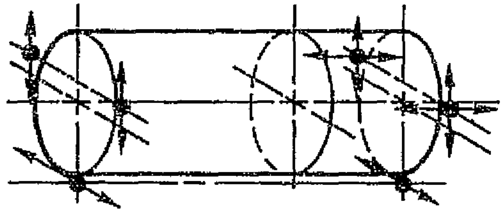
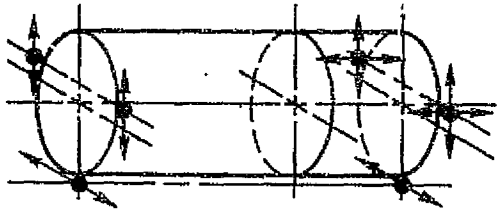
CONFIGURATION					SUPPORT LOCATIONS						
NO.	DESCRIPTION	ARRANGEMENT	OPTION	ADAPTER?	X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
4	DUAL FWD Z & DUAL Y X & FWD Z BALANCED		-1 -2 -3	YES NO YES	1246 1187 1246	1249 1181 1128	951 951 951	1246 1187 1128	1246 1187 1128	951 951 951	951 951 951
5	DUAL FWD Z & DUAL Y X & AFT Z BALANCED		-1 -2 -3	YES NO YES	1246 1187 1246	1249 1181 1128	951 951 951	951 951 951	951 951 951	1246 1187 1128	1246 1187 1128

Figure 4.2-15C. Doubly Redundant Load Balanced Support Arrangements

Figure 4.2-16 illustrates the redundant fluid system schematically and shows a bridge beam installation concept for balancing two forward Z supports.

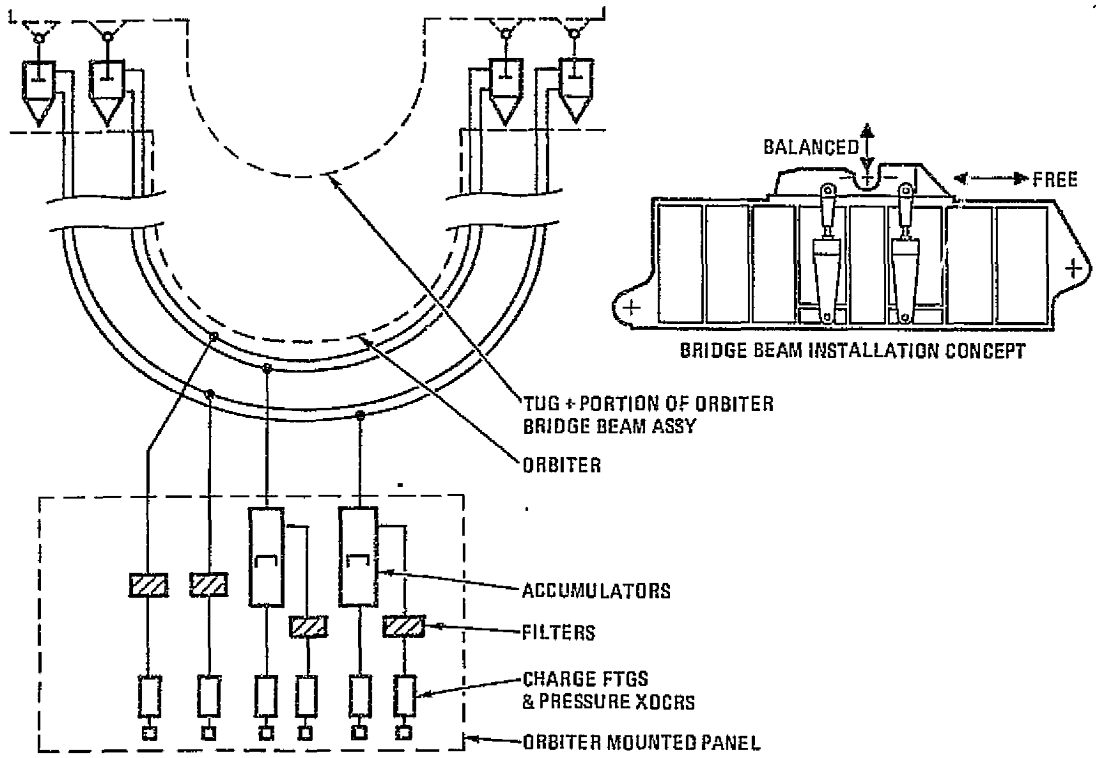


Figure 4.2-16. Load Balancing System Concept

4.2.2.2 Support Reaction Evaluation. The initial support reaction evaluation presented here was employed in the preliminary assessment and screening of the 21 support arrangement candidates developed in Section 4.2.2.1. (A special emphasis update task was conducted later for selected support arrangements and is discussed in Section 4.2.3.8.) This task was conducted in the sequence shown in Figure 4.2-17.

Each of the 21 candidate support arrangements was analyzed using an existing computer program to determine its maximum support reactions. The limit payload bay accelerations specified in MSFC 68M00039-1 were used in determining critical load conditions and the associated support reactions. To limit the number of computer runs for each support arrangement, the mass configurations (Tug + propellant + spacecraft versus mission type and phase) that were likely to produce maximum support reactions were identified. To obtain a measure of goodness for candidate screening, the computed reactions were compared with Orbiter capability as defined in JSC 07700, Vol. XIV, Rev. C and the resulting ranking of candidates was used in the candidate selection discussed in Section 4.2.2.4. Unfortunately the specified

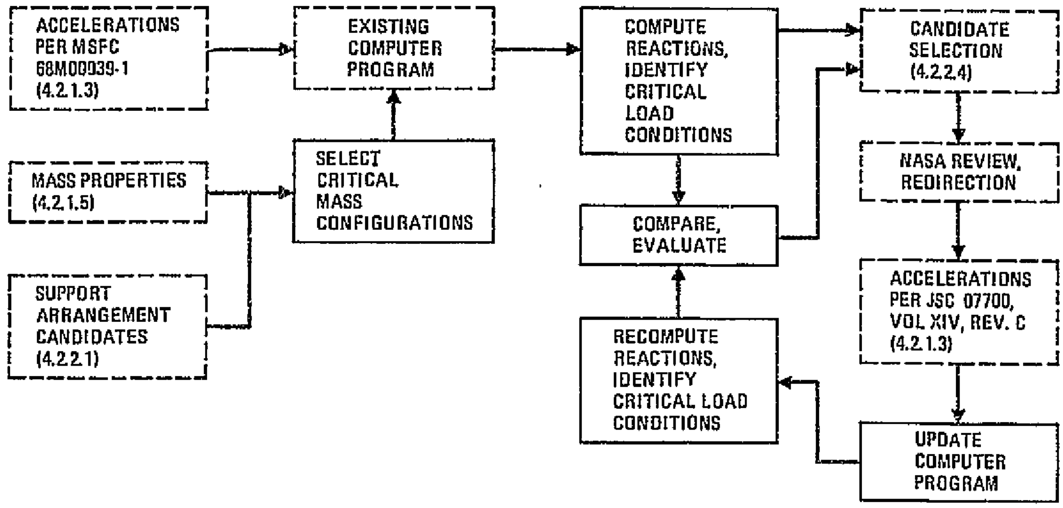


Figure 4.2-17. Support Reaction Evaluation Task Sequence

Orbiter capability was exceeded by every candidate support system for most or all of its reactions. Upon presentation of this data at the First Data Exchange meeting, direction was given to repeat the entire analysis using the Orbiter cargo bay accelerations specified in JSC 07700, Vol XIV, Rev. C, and to compare the two sets of support reactions. This redirection necessitated a substantial revision of the support reaction computer program to accept mass moment of inertia inputs and to incorporate the JSC angular acceleration components into the support reaction equations. Upon recomputation of the support reactions for all candidates a comparison with previous data was conducted, and the candidate selection was reviewed for possible revision.

Computer Program. A simplified logic flow and sample output from the support reaction computer program are shown in Figure 4.2-18. For a given support arrangement and mission type and phase (i.e., mass configuration) the program computed each support reaction for each acceleration case in the subset of accelerations corresponding to the given mission mode. As a given acceleration case was processed, each reaction was computed and compared with previously stored maximum (+) and minimum (-) values for that reaction, and, if greater, was stored in place of the previous value. The acceleration case number associated with a stored reaction value was also stored to permit identification of specific critical cases. Final printout consisted of the maximum numerical values (+ and -) and the corresponding acceleration case for each reaction component in the selected support arrangement. Comparison of similar output for other mission modes (using other mass configurations and/or acceleration case subsets) permitted definition of the maximum reaction magnitudes for a given support arrangement when subjected to all perturbations and combinations of accelerations within the complete set used.

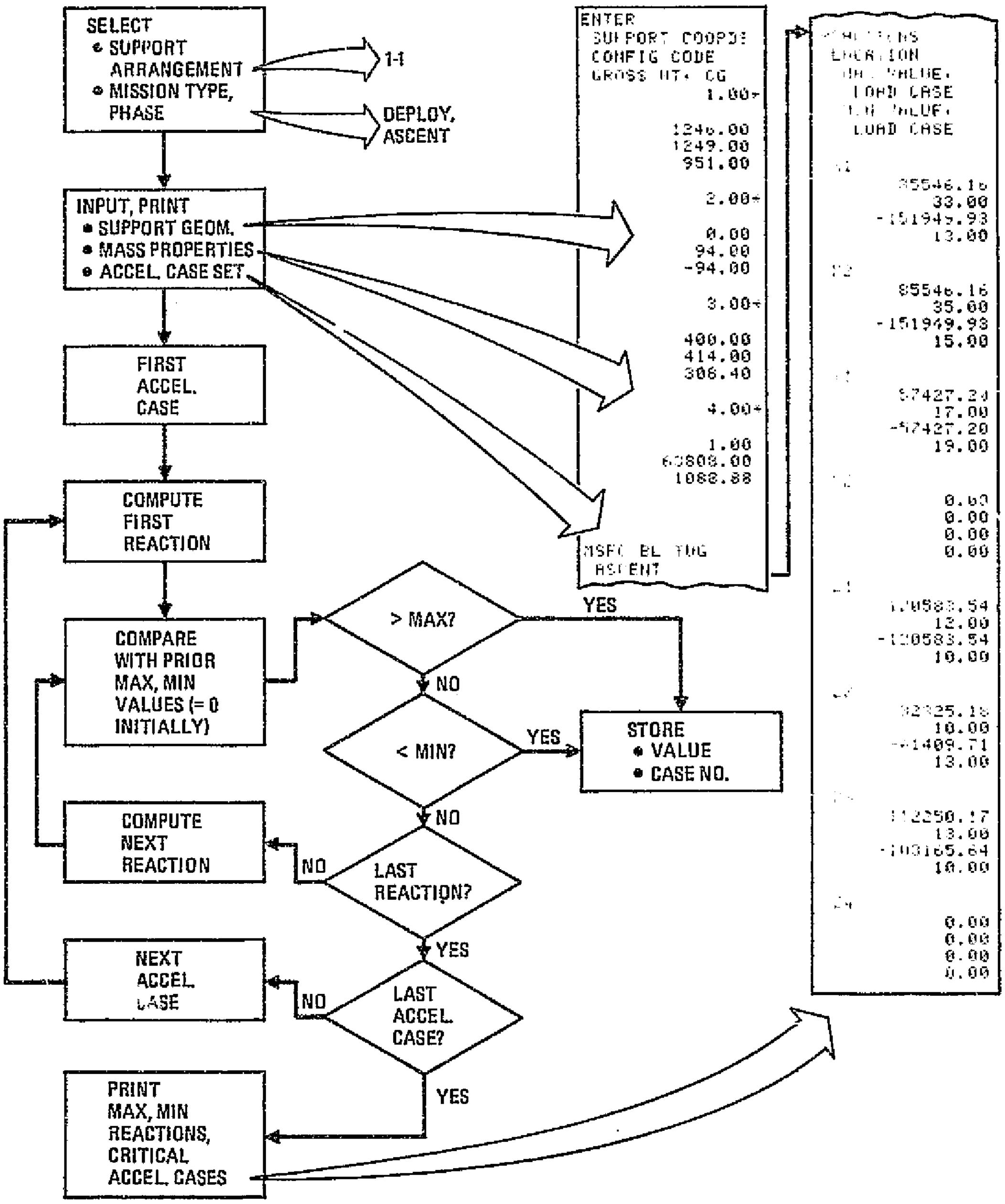


Figure 4.2-18. Support Reaction Program Logic and Sample Output

In the sample shown in Figure 4.2-18 the input data and maximum reactions are shown for support arrangement 1-1 (statically determinate family with rotational deployment using a load-carrying support adapter) for the ascent phase of a deployment mission (reference spacecraft and corresponding propellant off-load), when subjected to all acceleration cases specified in MSFC 68M00039-1. The reactions shown are those applied to the Tug (since the program was originally written to assist Tug structural analysis) and hence the signs must be reversed for loads applied to the Orbiter.

Critical Mass Configurations. As mentioned above, the number of mass configurations investigated for each support arrangement was limited by identifying critical mass configurations using the mass properties data from Section 4.2.1.5. The following ground rules and assumptions were adopted for this task:

a. Both propellant tanks are filled as full as possible (within the Orbiter weight limit) for each mission.

b. In abort, all main impulse oxidizer is dumped before descent.

c. In abort, main impulse fuel is not dumped.

d. In normal return to the Orbiter, all usable main impulse, ACPS, and fuel cell fluids are expended and/or dumped before descent.

e. Orbiter maximum cargo capability is 65,000 lb (29510 kg).

f. The reference Tug installation includes 1192 lb (541 kg) of Shuttle accommodation provisions not supported by the Orbiter primary payload support fittings.

g. The reference Tug installation, fully loaded, without spacecraft weighs 58,679 lb (26640 kg).

h. The heaviest retrieval spacecraft is EO-12 (Tiros O): 4740 lb (2152 kg).

i. The heaviest deploy spacecraft is the reference spacecraft (Section 4.2.1.4): 11,000 lb (4994 kg).

j. The heaviest multiple deploy-only spacecraft combinations are: CN-51 or CN-53 (3246 lb (1474 kg)) plus EO-09 or EO-59 or EO-62 (3376 lb (1533 kg)) for a total of 6622 lb (3007 kg).

k. The heaviest round-trip deploy spacecrafts are: CN-53 (3246 lb (1474 kg)) plus EO-57 (566 lb (257 kg)) for a total of 3812 lb (1731 kg).

l. The heaviest round-trip retrieval spacecraft is: CN-59 (2108 lb (951 kg)).

m. Crash after abort descent is a valid condition.

All resulting potentially critical mass configurations are shown in Table 4.2-4, and critical configurations are selected based on the table data and the following observations and conclusions.

Table 4.2-4. Definition/Selection of Critical Mass Configurations

Mission		Weights							Critical Configuration?		
		Expendables (lb)				Total*					
Type	Phase	Oxid	Fuel	ACPS+ F.C.	Spacecraft (lb)	lb	kg	CG X_o	Yes	No	Basis
Deploy only	Ascent	39,188	6694	463	~11,000	63,808	28,869	1088.88	X		10
	Descent (Nom.)	0	0	0	0	6,463	2,934	1107.91		X	9
	Crash (Nom.)	0	0	0	0	6,463	2,934	1107.91		X	12
	Descent (Abort)	0	6694	463	~11,000	24,620	11,177	946.24	X		13
	Crash (Abort)	0	6694	463	~11,000	24,620	11,177	946.24	X		12
Retrieve only	Ascent	43,199	7362	463	0	57,487	26,099	1147.58	X		11
	Descent (Nom.)	0	0	0	4,740	11,203	5,086	1001.41		X	13
	Crash (Nom.)	0	0	0	4,740	11,203	5,086	1001.41		X	12
	Descent (Abort)	0	7362	463	0	14,288	6,487	1066.74		X	13
	Crash (Abort)	0	7362	463	0	14,288	6,487	1066.74		X	12
Round trip	Ascent	43,199	7362	463	3,812	61,299	27,830	1131.02		X	7, 10
	Descent (Nom.)	0	0	0	2,108	8,571	3,891	1036.56		X	8, 13
	Crash (Nom.)	0	0	0	2,108	8,571	3,891	1036.56		X	8, 12
	Descent (Abort)	0	7362	463	3,812	18,100	8,217	1027.70		X	13
	Crash (Abort)	0	7362	463	3,812	18,100	8,217	1027.70		X	12

*Includes Tug burnout + adapter weights: 6463 lb (2934 kg).

1. From f, g: Maximum supported weight in the Orbiter for ascent without spacecraft (retrieval-only mission) = 58, 679 - 1192 = 57, 487 lb (26099 kg)

2. From 1, a: Supported weight in the Orbiter for ascent phase of all retrieval-only missions is 57, 487 lb (26, 099 kg).

3. From e, f: Maximum supported weight in the Orbiter for ascent with spacecraft (deploy-only or round-trip missions) = 65, 000 - 1192 = 63, 808 lb (28, 969 kg).

4. From 1, 3: Tug can carry spacecraft ≤ 6321 lb (2870 kg) without propellant off-load.

5. From 3, a: Supported weight in Orbiter for ascent phase of all deploy-only or round-trip missions exceeds 57, 487 lb (26, 099 kg), the upper limit being 63, 808 lb (28, 969 kg) (i.e., deploy-ascent weight > retrieve-ascent weight).

6. From 2, 5 and reference Tug + spacecraft physical relationship (spacecraft forward of Tug): CG of total supported weight is further forward for deploy-ascent than for retrieve-ascent.

7. From i, j, k: Reference spacecraft in i exceeds all other deploy spacecraft.

8. From h, l: Maximum retrieval spacecraft weighs 4740 lb (2152 kg).

9. From d: Normal descent after any nonretrieval mission is noncritical for reactions (empty Tug only).

10. From 5, 6: Deploy-ascent probably critical for forward reactions (forward CG + maximum weight).

11. From 2, 3, 6: Retrieve-ascent probably critical for aft reactions (aft CG + somewhat less weight).

12. From a, b, c, h, i, m: Crash after abort from deploy mission probably envelops all other crash cases.

13. From b, c, h, i, 7, 8, 9: Abort descent after deploy mission envelops all other descent cases (except possibly abort descent after retrieve ascent) and may be critical for all reactions (highest descent weight, most forward descent CG).

The resulting critical mass configurations are illustrated in Figure 4.2-19.

Reaction Computations, Comparison, and Evaluation. Support reactions were computed and maximum values determined using the computer program and mass

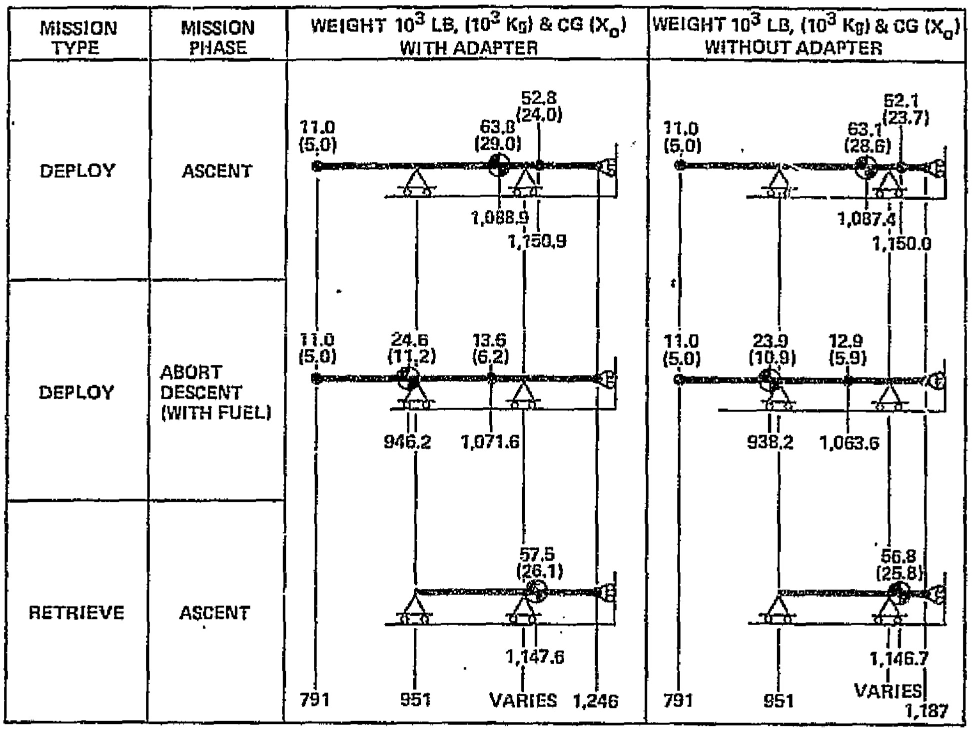


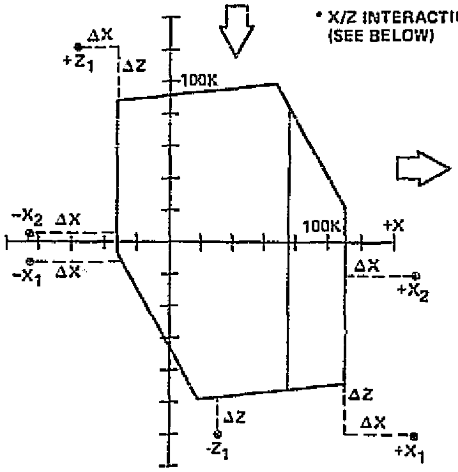
Figure 4.2-19. Critical Mass Configurations

configurations discussed above. To determine the relative unacceptability of the candidates, a technique was developed in which the excessive reaction magnitude was accumulated for each arrangement. This process is shown in Figure 4.2-20 for the same arrangement and acceleration set used for the sample in Figure 4.2-18. Computed maximum candidate reactions were tabulated versus Orbiter capability and, in the case of X and Z reactions at a single support point, were also plotted on a graph containing the allowable X/Z interaction envelope (reference Figure 4.2-9). The value by which the computed reaction magnitude exceeded the allowable capability was determined for each reaction, and the summation (accumulation) of all elements of reaction exceedance was determined as shown. Repeating this process for each support arrangement candidate using the MSFC 68M00039-1 accelerations resulted in the accumulated exceedance summations and ranking shown.

For purposes of comparative assessment, configurations exhibiting the lowest exceedance were judged best from the standpoint of Orbiter compatibility, since they tended to imply least potential Orbiter impact. However, it was recognized that an absolute correlation between ranking and Orbiter weight and/or cost impact could not be justified since the various elements of exceedance occurred in different proportions among the 21 configurations and the nature and extent of the weight and cost impact associated with each was unique.

CONFIG		REACTIONS (1,000 LB)								
		X_1 & X_2		Y_1	Z_1		Z_2		Z_3	
		+	–	±	+	–	+	–	+	–
1-1	MAG	152.0	85.5	57.4	120.6	120.6	60.4	52.2	103.2	112.3
	ORB CAP	*	*	56	*	*	*	*	52	67

* X/Z INTERACTION (SEE BELOW)



ACCUMULATED EXCEEDANCE	
X ONLY	–
X IN X/Z	216.0
Y	1.4
Z ONLY	96.5
Z IN X/Z	31.0
Σ	344.9

COMPARATIVE ASSESSMENT		
CONFIG.	Σ	RANKING
1-1	344.9	16
1-2	243.4	6
2-1	193.4	2
2-2	213.0	3
2-3	287.6	12
3-1	341.5	15
3-2	282.4	11
3-3	409.5	18
4-1	266.0	9
4-2	239.0	4
4-3	266.4	10
5-1	250.6	7
5-2	184.0	1
5-3	242.6	5
6-1	430.7	19
6-2	365.7	17
7-1	678.0	20
7-2	617.2	21
8-1	338.6	14
8-2	256.0	8
8-3	317.4	13

Figure 4.2-20. Determination of Support Reaction Accumulated Exceedance

The exceedance ranking was used in Section 4.2.2.4, in conjunction with other evaluation criteria, to select four recommended support arrangements for further detailed study. (For reference in the following discussion, the selected arrangements were 1-1, 1-2, 2-1, and 2-2.)

Since all support configurations exhibited substantial exceedance (Σ_{Min} = 184.0K) using accelerations per MSFC 68M00039-1 to compute reactions, the comparison with reactions computed using accelerations per JSC 07700, Vol. XIV, Rev. C, was conducted. The resulting comparison is summarized in Table 4.2-5. Backup data for the support reaction computations is included in Appendix B.

The accumulated exceedance using JSC accelerations is less in all 21 support configurations with substantial reductions in most.

Two configurations (4-1, 4-2) exhibit zero exceedance using JSC accelerations and Σ < 50K for seven others. The five best configurations, however, are either doubly redundant or require dual hydraulic load balancing systems to decouple the redundant supports and provide statical determinacy. Consequently, they tend to be heavier, more costly, and lower performing than the four previously recommended systems. The four recommended systems all slipped in the overall rankings, and in each case the exceedance is determined almost entirely by high X reactions (which are nonetheless lower than those due to MSFC accelerations).

Table 4.2-5. Support Reaction Exceedance Comparisons

Configuration		Exceedance Comparisons					
		MSFC*		JSC*		1128Y	
No.	Redundancy	Σ	Ranking	Σ	Ranking	MSFC*	JSC*
1-1	0	344.9	16	218.1	18	352.7	61.7
1-2		243.4	6	41.6	9	279.9	13.9
2-1	1	193.4	2	184.8	17	311.0	66.4
2-2		213.0	3	29.2	8	259.4	11.4
2-3		287.6	12	143.8	14		
3-1	1	341.5	15	17.3	7		
3-2		282.4	11	16.5	6		
3-3		409.5	18	121.3	11		
4-1	2	266.0	9	0	1		
4-2		239.0	4	0	1		
4-3		266.4	10	92.4	10		
5-1	2	250.6	7	14.6	5		
5-2		184.0	1	3.2	3		
5-3		242.6	5	8.2	4		
6-1	0	430.7	19	172.7	16		
6-2		365.7	17	125.7	12		
7-1	0	578.0	20	242.9	20		
7-2		617.2	21	250.9	21		
8-1	1	338.6	14	229.7	19		
8-2		256.0	8	160.6	15		
8-3		317.4	13	130.6	13		

*Ref: MSFC 68M00039-1, Figure 6
JSC 07700, Vol. XIV, Rev. C, Table 7.6

To minimize X reactions in the selected configurations, new derivative arrangements were investigated. In each of these the only change was relocation of the Y support to an Orbiter support location within the CG excursion band for heavy (i.e., deploy ascent and retrieve ascent) mass configurations. The only support location satisfying this requirement is at X_o 1128. The resulting accumulated exceedances are also shown in Table 4.2-5. For the MSFC accelerations, the exceedance worsened in all four configurations in spite of reductions in $\pm X_{max}$. This resulted from increases in the X reactions interacting with the maximum aft Z reactions. For the JSC accelerations, all four configurations improved substantially.

The selection of a preferred Tug support arrangement and the extent of the associated Orbiter modification, if any, depended upon the adoption of a realistic set of cargo bay accelerations for subsequent structural interface analyses. However, it was not clear that either of the above acceleration sets was appropriate. For example, the JSC accelerations did not include any allowance for dynamic response of the cargo (Tug + spacecraft), yet infinite rigidity is unattainable and hence some dynamic response will occur and allowance must be made for it. Conversely, the MSFC accelerations included allowance for cargo dynamic response, but these same data had been specified for both LST and the Tug, whose response characteristics are probably quite different, and their applicability to Tug was therefore uncertain. It was therefore recommended that the appropriate acceleration values be determined for an envelope of combined Orbiter/ Tug/spacecraft combinations.

It was decided that until such analyses were completed the MSFC data should be assumed to represent the best available data and that Tug support reactions (and the resulting exceedance) should continue to be based upon it. However, it was also felt that the (TBD) correct accelerations probably lay between the JSC and MSFC values (since certain MSFC cases with high pitch accelerations produce intolerable conditions, such as lateral load on the full oxidizer tank equivalent to landing full, which might require Shuttle system changes to provide alleviation), and the resulting reactions would probably include some exceedance of current Orbiter capability (since only two of the configurations have 0 exceedance with current JSC accelerations). Consequently the following recommendations were made:

a. The four selected configurations should be retained.

b. The Y support should not be moved to X_o 1128 at this time, but the Δ weight and Δ performance impacts of doing so should be determined.

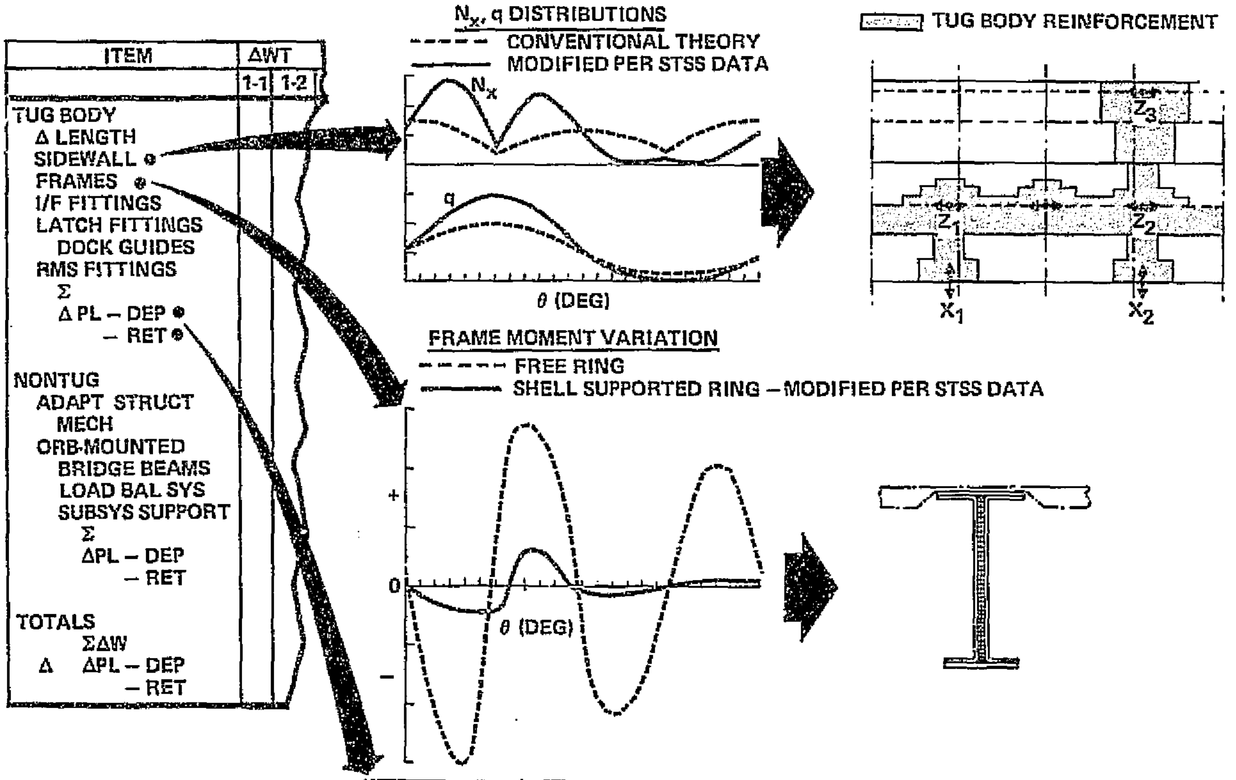
c. JSC and Rockwell International should investigate (parametrically, as a function of reaction magnitude) the impact of providing the capability to accommodate support reactions beyond current Orbiter capability at those locations potentially usable by Tug. Maximum reactions at each location should at least equal, and preferably exceed, somewhat, those computed using MSFC accelerations in the four recommended configurations.

d. Prediction of Tug/spacecraft dynamic response should be undertaken as soon as possible so that a suitable set of cargo bay accelerations could be determined, permitting selection of a preferred support arrangement based on further assessment of Tug and Orbiter impacts.

4.2.2.3 Weight/Performance Evaluation. Weight/performance evaluations were conducted for each candidate support arrangement using the method shown in Figure 4.2-21. The itemized weight tabulation shown includes all items expected to vary in weight or location as a function of support arrangement and/or Tug/adapter configuration. Support arrangement 6-1 was assumed as a baseline for the Δ-weight and Δ-performance computations.

Detailed analyses of the Tug sidewall and major frames were conducted. Initial body loads were developed by computer using conventional engineering theory. These were then modified to account for axial force and shear flow peaking near the support reactions and for frame moment damping due to shell support. Existing Tug finite element model data generated in the STSS provided the basis for the load modification.

The reference configuration for both the support adapter sidewall (reference Section 4.2.3.5) and the additional length required to extend the Tug to the X_0 1187 support station (in configurations without support adapter) (reference Figure 4.2-7A) were



MISSION	∂PL/∂WTUG	∂PL/∂W NONTUG
SYNCH DEPLOY	-2.62	-0.38
SYNCH RETRIEVE	-1.38	0

Figure 4.2-21. Weight/Performance Evaluation Method

based on extension of the reference Tug sidewall sandwich (reference Figure 4.2-5) with appropriate allowance for nonoptimum weight items. Weights of interface fittings, adapter mechanisms, and Orbiter bridge beams were taken from STSS and Rockwell International data. Latch longerons were sized to carry the appropriate tensile loads resulting from the modified body loads data. The X and Z load balancing systems consisted of hydraulic systems including cylinders, accumulators, lines, fluid, and various fittings (reference Figure 4.2-16) plus Δ weight allowances in the Orbiter bridge beams to accommodate system installation. Partial derivatives used for Δ performance computations were taken from MSFC 68M00039-2.

Tug Body Δ Length. The Tug body aft extension was incorporated in the -2 configuration option in all support arrangement families to accommodate Tug/Orbiter interface provisions at X_0 1187 (X/Z supports) and X_0 1181 (Y-support) (reference Section 4.2.1.1, Figure 4.2-7A). The reference configuration for the sidewall extension is shown in Figure 4.2-21A. Region 2 is an 8.4 in. (21.3 cm) span of basic sandwich sidewall whose cross section is identical to that shown in Figure 4.2-5 for the reference Tug body. Regions 1 and 3 are transition sections identical to the solid laminate pan concept shown in Figure 4.2-6. Table 4.2-6 presents the weight summary for the reference configuration body extension (excluding reinforcement for load peaking).

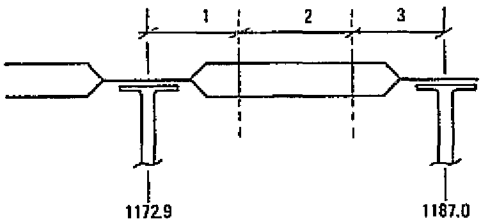


Figure 4.2-21A. Tug Body Aft Extension

Sidewall Reinforcement Correction Factors for Load Peaking. Because of the method of Tug support in the Orbiter, "conventional" engineering theory (P/A + Mc/I and VQ/I + T/2A) does not give the proper stress distribution in the Tug structural shell. For preliminary sizing a rational method of modifying the conventional theory internal loading

Table 4.2-6. Weight Summary for Aft Body Extension

Item	Weight lb	Weight kg	Comment
1	11.57	5.25	Includes 20% allowance for nonoptimum weight items (potting, tolerances, etc.)
2	17.53	7.96	
3	16.03	7.28	
4	20.00	9.08	Allowance for local provisions for Y-reaction introduction
Σ	65.15	29.57	

distribution to more closely agree with actual distribution was required. Results from the STSS computer analysis of Tug internal loads were therefore used to generate correction factors that could be applied to the conventional theory shell loads.

Axial line loading in the Tug structure is generated by side bending (M_Z), vertical bending (M_Y), and axial loading (P_X). Since the Tug configurations and loading conditions introduce variations in the combination of M_Y, M_Z, and P_X, each of the loads had to be corrected individually, then superimposed to obtain a total corrected shell line loading (N). The following procedure was employed to accomplish this correction.

a. Calculated conventional theory line loading distributions at stations of interest.

b. Applied a correction factor to N such that:

$$N_{TRUE} = K\, N_{THEORY}$$

using curves for K versus Θ at stations of interest.

Axial Loading (P_X)

The peaking due to the two X reactions is a maximum at the X supports and drops off to conventional theory distribution approximately 280 in. (711 cm) from the X supports, as shown for K_{NPX} in Figure 4.2-22. Distribution around the circumference at any station was obtained by using the equation shown.

Vertical Bending (M_Y)

The peaking due to M_Y is due to the single (offset) forward vertical support, which causes peaking on the shell structure adjacent to the support. Based on the STSS computer analysis, this peaking carries on for a considerable distance from the single vertical support. Therefore, K_{NMY} from Figure 4.2-22 was used for half the distance from a single vertical support to the symmetrical vertical supports. Conventional theory was used for the remainder of the shell. Note the peaking effect applies only in configurations with a single vertical support. Conventional theory was used in configurations with symmetrical vertical supports.

Side Bending (M_Z)

Because of the vertical offset between the side (Y support) reaction and vehicle axis, torsion occurs in the structure in addition to bending for side loading. This torsion is not reacted entirely by T/2A shear but also is reacted by differential bending of the shell. This differential bending modifies the conventional theory bending stress distribution. Figure 4.2-22 was used to modify the theoretical distribution. Based on STSS computer loads, this peaking effect extends a significant distance from the

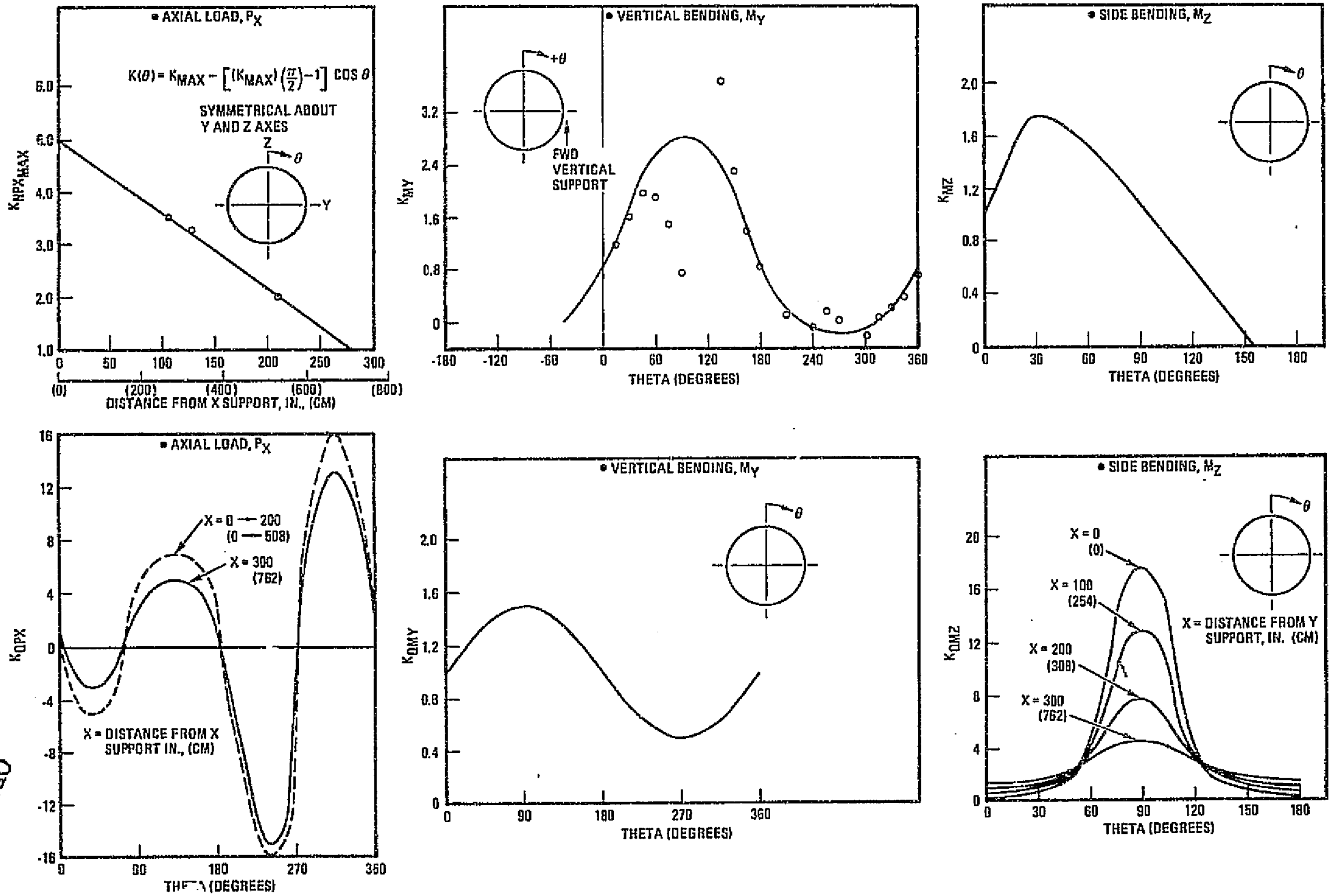


Figure 4.2-22. Peaking Factors for Axial Force (K_N) and Shear Flow (K_Q)

side support. For preliminary sizing, the full peaking effect was used for 280 in. (711 cm) from the side support and conventional theory was used beyond.

c. Calculated the combined corrected N at points of interest:

$$N_{TRUE} = \Sigma (K \cdot N_{THEORY})$$

Shear flow correction was accomplished in a manner similar to the above axial load correction. The coefficients used were K_{QPX}, K_{QMY}, and K_{QMZ}, and their distributions are also given in Figure 4.2-22. Combined, corrected q was calculated at points of interest by:

$$q_{TRUE} = \Sigma (K \cdot q_{THEORY})$$

"Conventional Theory" Body Loads. A Hewlett-Packard computer program was written to compute and plot n_x and q at 15-degree increments around the Tug circumference at any selected station for any support configuration. Mass properties input consisted of the weight and CG forward of the selected station and was based on the weight and CG accumulations shown in Figures 4.2-12E, -12F, and -12G.

The program contained a mode select option, permitting individual acceleration cases to be input from the keyboard or multiple-case subsets to be loaded directly into storage as the program was loaded (as in the support reaction program previously discussed in Section 4.2.2.2). In the latter mode only the + and - maxima of n_x and q, at each point, considering all acceleration cases in the subset, were retained for plotter output (i.e., the resulting plots were envelopes of $\pm n_x$ and $\pm q$ maxima considering all cases). This was accomplished using the same max/min storage logic illustrated in Figure 4.2-18 for support reaction computation.

By first plotting the envelopes at a given station, then overplotting the probable responsible individual load cases, the envelopes were readily mapped and the critical cases (and the areas they govern) defined. Support arrangement 6-1 was used as the baseline for identification of critical acceleration cases, which were then assumed to apply to all support arrangements.

Table 4.2-7 summarizes the critical cases (within the MSFC 68M00039-1 acceleration set) and identifies the areas governed. Parenthetical terms indicate a local portion of the circumference governed by the noted condition.

Using the acceleration case subsets within the critical load conditions, body load envelopes were generated for all 21 support arrangements at Stations X_0 952, 1063, 1127, 1172, and either 1186 or 1246. These were then modified to better approximate the actual load distributions by using the appropriate peaking factor(s) from Figure 4.2-22. Figure 4.2-23 shows the initial "conventional theory" axial force and

Table 4.2-7. Critical Conditions for Body Loads

Mission			Regions Governed[1]			
			Axial Force		Shear Flow	
Type	Phase	Load Condition	$+n_x$	$-n_x$	$+q$	$-q$
Deploy	Ascent	Launch Release	F M	F M	F (M)	F M
		Max Q				
		SRM Cutoff	A, (M)	A		(M)
Deploy	Abort Descent	Reentry	F (M) A	(F)	F M	F
Retrieve	Ascent	Launch Release	(M)	(M)	M, A	F, M, A
		Max Q				
		SRM Cutoff	(A)	(A)		

(1) F = Fwd. Body (936-1062); M = Mid Body (1062-1173); A = Aft Body, Incl Adapter (1173-1249)

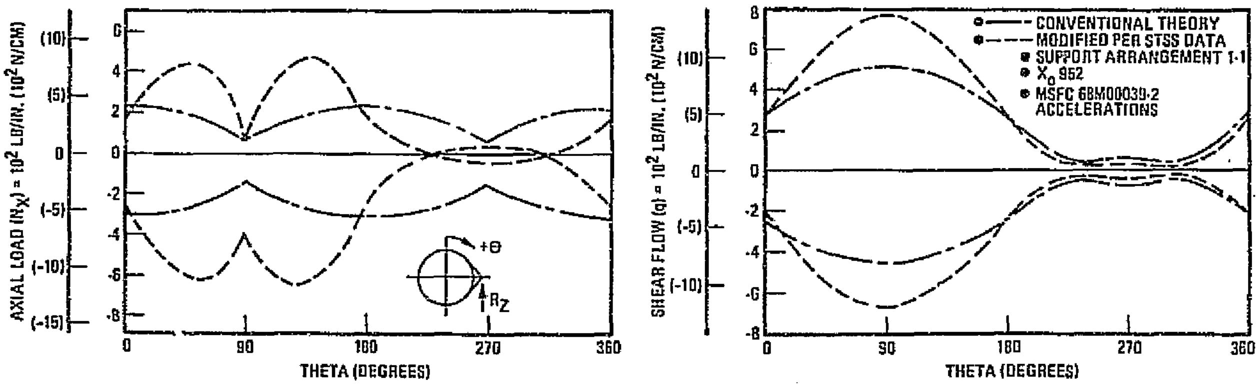


Figure 4.2-23. Body Loads Distributions

shear flow envelopes and the corresponding modified distributions at Station X_0 952 for support arrangement 1-1 using accelerations from MSFC 68M00039-1.

Resizing. Determination of the facing thickness increases and their region of effectivity on the Tug body surface was accomplished by the following method:

a. Used the conventional theory H. P. computer plots modified by appropriate peaking factors to obtain axial (N) and shear (q) loading for sizing shell.

b. Used maximum shear and axial envelopes for combined allowables. Used interaction equation

$$M.S. = \frac{1}{\sqrt{R_A^2 + R_S^2}} - 1 \text{ to size body shell for combined loading}$$

c. Used reference configuration sandwich sidewall (Figure 4.2-5) as baseline.

d. Added plies at selective locations as required in two ply increments (one ply/face). Added plies at ±45 or 0 degrees, depending on whether shear or axial load was critical.

e. Selected appropriate facing layup using limit allowables (Table 4.2-8).

f. Mapped regions of Δ thickness onto Tug body flat pattern and smoothed step boundaries to allow for probable manufacturing simplification. Figure 4.2-24 shows the resulting body reinforcement pattern for support arrangement 1-1.

In addition to the reinforcement mentioned above, the -2 options in each support arrangement family required further reinforcement along the X-support longerons between X_0 1128 and 1187. An additional reinforcement of twelve plies per face was required to accommodate the added limit shear flow along the longerons. This was assumed to step-taper to the previously computed facing thicknesses ±22.5 degrees from each longeron, as shown in Figure 4.2-25.

Reinforcement Weights. The total weight of all sidewall reinforcement for the 21 support arrangements is shown in Table 4.2-9. The Δ-weight relative to MSFC baseline arrangement 6-1 is also tabulated.

Frames. In a manner similar to that used for body load correction factors, Tug frame bending moment and shear coefficients were derived from the STSS finite element computer solutions. Figure 4.2-26 illustrates the moment and shear coefficients.

Table 4.2-8. Sandwich Limit Allowables for In-Plane Loads

Facing Configuration[1]			Limit Allowables[2]					
			Axial Force (n_x)				Shear Flow (a)	
			Tension		Compression			
Layup	Orientation	Plies	lb/in.	N/cm	lb/in.	N/cm	lb/in.	N/cm
Baseline[3]	$0_3/\pm45$	5	1157	2025	723	1265	321	562
Baseline + 1 @ 0°	$0_4/\pm45$	6	1478	2587	918	1607	305	534
Baseline + 2 @ 0°	$0_5/\pm45$	7	1845	3229	1147	2007	360	630
Baseline + 1 @ 45°	$0_3/+45_2/-45$	6	1196	2093	809	1416	444	777
Baseline + 2 @ 45°	$0_3/\pm45_2$	7	1237	2165	765	1339	596	1043
Baseline + 3 @ 45°	$0_3/+45_3/-45_2$	8	1234	2160	734	1285	733	1283
Baseline + 1 @ 0° + 2 @ 45°	$0_4/\pm45_2$	8	1594	2790	909	1591	604	1057

(1) Per individual facing; facings symmetrical about sandwich center line.

(2) Per pair of facings.

(3) Per Section 4.2.1.1, Figure 4.2-5.

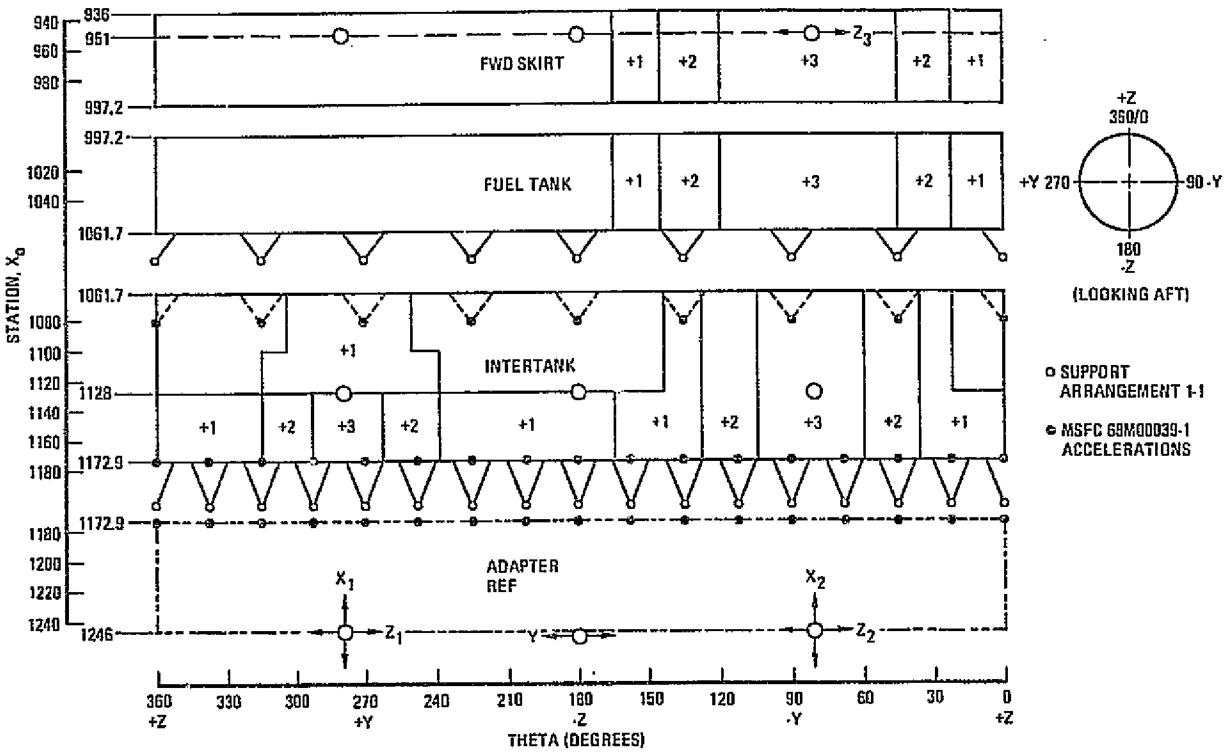


Figure 4.2-24. Body Reinforcement Pattern

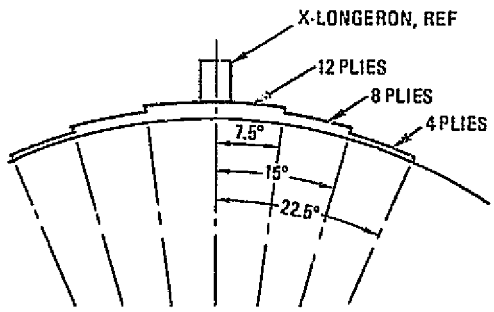


Figure 4.2-25. Local Reinforcement Under X-Support Longerons

Tug frame bending moment distributions were then obtained by multiplying these moment coefficients by the maximum support reactions on each frame in each support arrangement. The resulting moment distribution at X_O 951 in support arrangement 1-2 is shown in Figure 4.2-27.

Review of the preceding frame moments after smoothing versus those for a free ring subjected to the same loads indicated both a substantial reduction of peak moments and a narrowing of the affected arc, as shown in Figure 4.2-28. This was mainly due to sidewall shear restraint and indicated that lighter frames than those previously selected would be adequate for resisting the moments induced by Orbiter support reactions.

If frame weights were reduced, however, the analogy with the STSS configuration (on which the moment reductions were predicated) would no longer have been valid unless

Table 4.2-9. Tug Sidewall Reinforcement Weight

Support Arrangement	Reinforcement Δ-Weight (lb)				Total		Δ From 6-1	
	Fwd Skirt	Fuel Tank	Intertank	Aft ΔL	lb	kg	lb	kg
6-1	8.82	9.28	20.06	0	38.16	17.32	0	0
6-2	8.82	9.28	27.03	6.41	51.54	23.40	+13.38	+ 6.07
1-1	8.82	9.28	19.30	0	37.40	16.98	- 0.76	- 0.35
1-2	8.82	9.28	26.91	7.01	52.02	23.62	+13.86	+ 6.29
7-1	8.08	9.28	21.94	0	39.30	17.84	+ 1.14	+ 0.52
7-2	8.08	9.28	27.03	7.09	51.48	23.37	+13.32	+ 6.05
2-1	2.20	2.32	13.30	0	17.82	8.09	-20.34	- 9.23
2-2	2.20	2.32	19.43	6.67	30.62	13.00	- 7.54	- 3.42
2-3	2.20	2.32	11.14	0	15.66	7.11	-22.50	-10.22
8-1	6.60	5.96	15.80	0	24.36	12.88	- 9.80	- 4.45
8-2	6.60	5.96	21.01	6.67	40.24	18.27	+ 2.08	+ 0.94
8-3	6.60	5.96	13.64	0	26.20	11.89	-11.96	- 5.43
3-1	8.82	9.28	16.62	0	34.68	15.74	- 3.48	- 1.58
3-2	8.82	9.28	26.13	5.49	49.72	22.57	+11.56	+ 5.25
3-3	8.82	9.28	19.52	0	37.62	17.08	- 0.59	- 0.25
4-1	2.20	2.32	12.42	0	16.94	7.69	-21.22	- 9.63
4-2	2.20	2.32	17.89	5.83	28.24	12.82	- 9.92	- 4.50
4-3	2.20	2.32	9.18	0	13.70	6.22	-24.46	-11.10
5-1	6.60	5.96	14.48	0	27.04	12.28	-11.12	- 5.05
5-2	6.60	5.96	19.13	5.49	37.18	16.88	- 0.98	- 0.44
5-3	6.60	5.96	9.64	0	22.20	10.08	-15.96	- 7.25

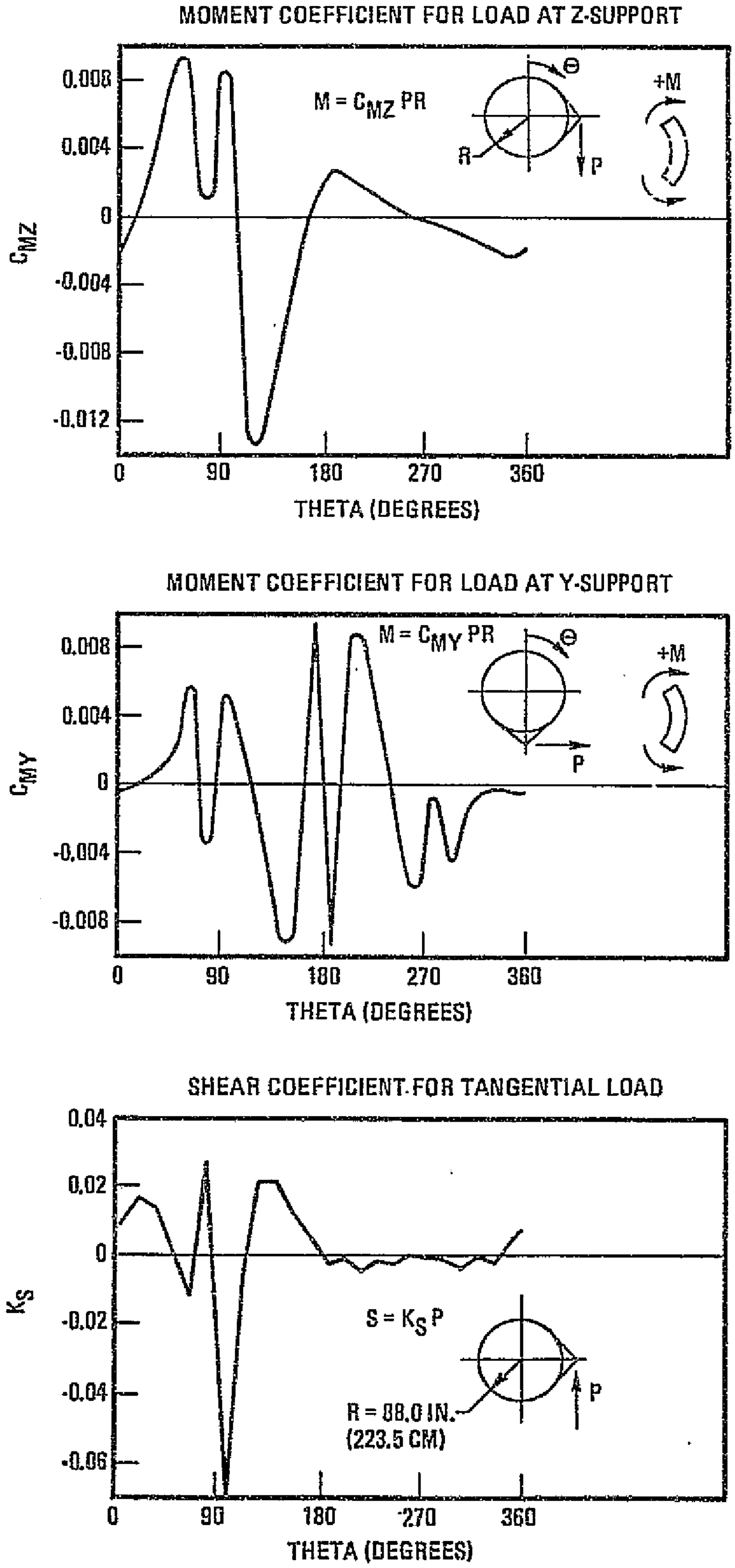


Figure 4.2-26. Frame Moment and Shear Coefficients

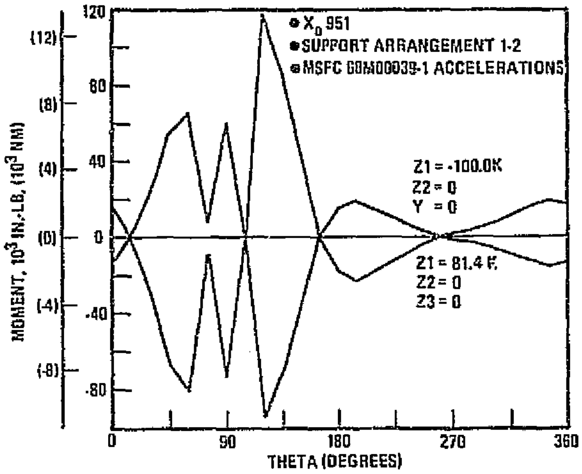


Figure 4.2-27. Tug Frame Bending Moment Distribution

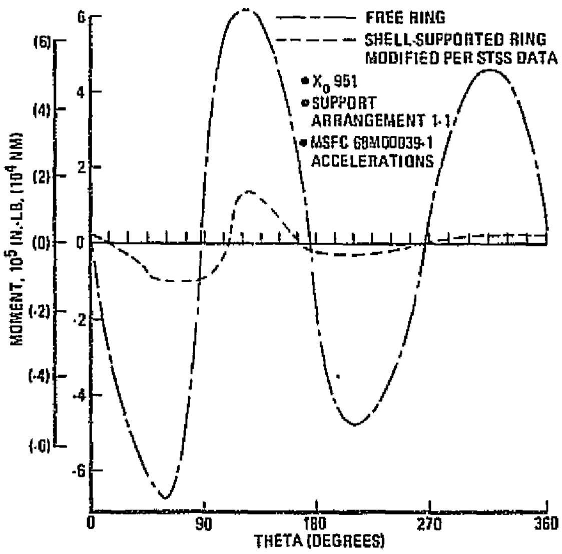


Figure 4.2-28. Effect of Shell Support on Frame Moments

a ratio of frame bending stiffness to shell shear stiffness was maintained similar to that in the STSS. Since the current sidewall material and construction was similar to the STSS, frame EI had to approximate that used in STSS. However, since frame weight reduction was accompanied with depth reduction to maintain balanced proportions, the moment of inertia also decreased. To maintain EI, an increase in E was therefore necessary. Since the STSS frames were aluminum, the required modulus increase could be achieved by using high-modulus graphite/epoxy for the current frames. Accordingly, the frame concept shown in Figure 4.2-29 was incorporated at all major load locations in the Tug and adapter. Code numbers shown refer to corresponding items in the following assumptions and method used for frame sizing.

1. Used high-modulus graphite/epoxy (HMS/X-904 or equivalent) for all solid laminate elements.

2. Used sandwich construction for the web with Hexcel HRP core.

3. Used a scrim reinforced adhesive for the the web channel/core bond.

4. Introduced radial loads into the frames using back-to-back aluminum fittings. For the portion of web between the fittings used solid laminate to permit mechanical attachment.

5. Introduced tangential loads into the frames through the outboard cap + effective material in an assumed "pan" in the body sidewall sandwich. Provided back-to-back reinforcing channel doublers.

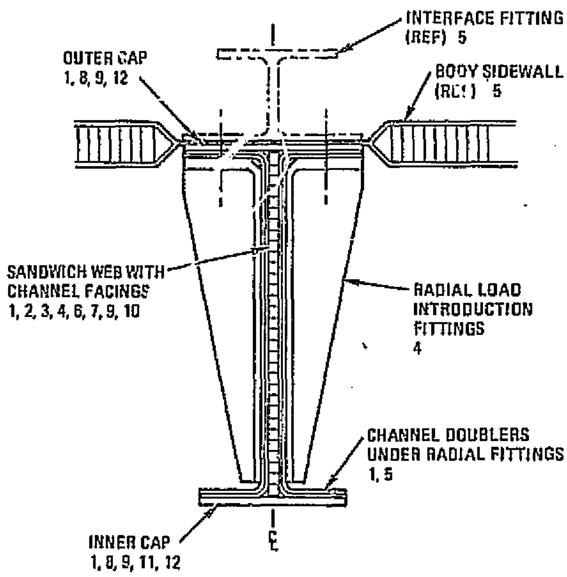


Figure 4.2-29. Major Frame Concept

6. Provided web reinforcement to accommodate high shear flows in the web adjacent to the load introduction points. Determined the arc extent of this material from the frame shear coefficient plot in Figure 4.2-26.

7. Assumed the web channel facings were limited to a minimum thickness of 0.009 in. (0.0225 cm) (4 plies), with 100 percent ±45-degree ply orientation.

8. Used 100 percent unidirectional ply orientation in the caps except for the web channel plies (which should be conservatively omitted in flange thickness determination).

9. Used $F.S._{ULT} = 1.4$ and $M.S. = +0.25$ in determining the allowable operating stresses for both flange and web material.

10. From item 9, the shear flow capability of the nominal web (item 7) was 443 lb/in. (775 N/cm), and the item 6 reinforcement was sized to carry shear flows in excess of this value.

11. Proportioned frame inner caps to achieve fully effective flange material per Roark, p. 139.

12. Used equal area in inner and outer caps, and held outer cap width constant at 3.00 in. (7.5 cm).

Since support reactions, and therefore moments, varied with both support location and arrangement, basic frame weights were developed parametrically. Figure 4.2-30 presents frame weight versus moment and includes allowances for potting and thickness tolerance. Similarly, the weight of local load introduction provisions on a given frame depended on the number and magnitude of support reactions carried by that frame. Figure 4.2-31 provides the weight of the local provisions parametrically for both Y and Z reactions for two frame depths.

Based in part on the parametric (moment) data and in part on the cap proportions versus depth, a baseline frame depth of 6.0 in. (15.2 cm) was selected. Flange areas were based on this depth in all frames. At locations with single Z reactions, the frame depth was increased to 8 in. (20.3 cm), with cap areas still based on 6 in.

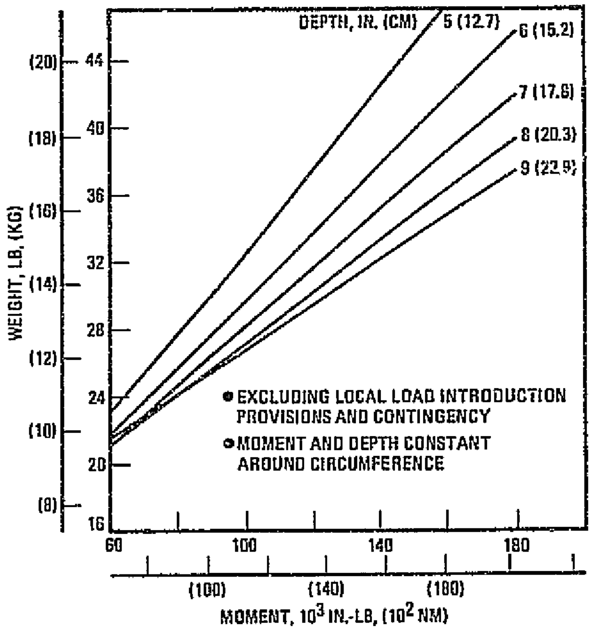


Figure 4.2-30. Frame Weight versus Moment

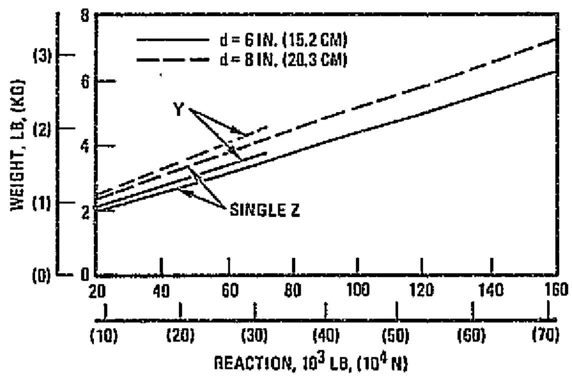


Figure 4.2-31. Weight of Frame Local Load Introduction Provisions versus Support Reaction

(15 cm) depth, to provide an increase in I of approximately 80 percent ·· these frames tend to be stiffness cri. per the STSS data. The added increment of web weight was 2.64 lb (1.20 kg).

The total frame weight at any location was determined as follows.

a. Divided the moment envelope curves into regions of constant moment.

b. Determined the weight of each region on the basis of $\Theta/360 \times$ the total frame weight for that moment from Figure 4.2-30.

c. Added the weight of local load introduction provisions for each reaction location.

d. Added $\Sigma b + \Sigma c$ to obtain the total weight and increased by 10 percent for contingency.

e. Added the Δ-web weight if appropriate.

The resulting Tug frame weights at Stations X_o 951, 1128, and 1187 are shown in Tables 4.2-10, -11 and -12 respectively.

Tug Fittings. From Figure 4.2-21, three types of fittings are mounted on the Tug body: 1) the primary support fittings at the Tug/Orbiter interface, 2) the longerons backing up the latches at the Tug/adapter separation plane (including any docking alignment provisions on the Tug side), and 3) a receptacle for the end effector on the Orbiter RMS.

Interface Fittings. Support fitting design was not conducted until the detailed assessment phase of the study (Section 4.2.3.3). In the interim, support fitting weights were taken from existing data. The two available sources were the NASA baseline Tug per MSFC 68M00039-2 and the Program 2 Tug per the Convair STSS. Table 4.2-13

Table 4.2-10. Frame Weights at X_0 951

Support Arrangement	Weights					Totals	
	Basic Frame	Δ For Stiffness	Δ at Z_3 Support	Δ at Z_4 Support	Δ at Y Support	lb	kg
6-1	25.71	2.64	5.10	-	-	33.45	15.19
6-2	25.81	2.64	5.20	-	-	33.65	15.28
1-1	25.86	2.64	5.50	-	-	34.00	15.44
1-2	25.50	2.64	5.30	-	-	33.44	15.18
7-1	34.10	-	5.00	3.20	3.30	45.60	20.70
7-2	38.75	-	5.00	4.10	3.30	51.15	23.22
2-1	21.70	-	3.00	3.00	-	27.70	12.58
2-2	21.70	-	2.70	2.70	-	26.40	11.99
2-3	21.70	-	2.70	2.70	-	26.40	11.99
8-1	32.00	-	3.80	3.80	3.30	42.90	19.48
8-2	29.40	-	3.50	3.50	3.30	39.70	18.02
8-3	25.70	-	3.10	3.10	3.30	35.20	15.98
3-1	25.42	2.64	5.5	-	2.90	36.46	16.55
3-2	25.21	2.64	5.3	-	2.50	35.65	16.19
3-3	25.21	2.64	5.3	-	2.50	35.65	16.19
4-1	21.9	-	3.0	3.00	2.3	30.2	13.71
4-2	21.7	-	2.8	2.80	2.0	29.30	13.30
4-3	21.7	-	2.8	2.80	2.0	29.30	13.30
5-1	28.56	-	3.8	3.80	2.5	38.66	17.55
5-2	26.56	-	3.5	3.50	2.2	35.76	16.24
5-3	23.16	-	3.1	3.10	2.0	31.36	14.24

compares the weights for the four types of fittings occurring in the various support arrangements. The STSS data was adopted since it included weights for all four fitting types, whereas the NASA data was limited to only those fitting types mounted on the baseline Tug body.

Latch Longerons and Docking Guides. Longerons are required in 16 places in configurations using a load-carrying support adapter to collect and transmit Tug inertia

Table 4.2-11. Frame Weights at X_o 1128

Support Arrangement	Weights				Totals	
	Basic Frame	Δ at Z_1 Support	Δ at Z_2 Support	Δ at Y Support	lb	kg
6-1	41.60	5.75	5.0	3.30	55.65	25.27
6-2	41.00	5.6	4.9	3.30	54.80	24.88
2-3	37.60	5.2	5.2	3.30	51.30	23.29
3-3	41.6	5.25	5.0	3.30	55.65	25.27
4-3	37.6	5.2	5.2	3.30	51.30	23.29
5-3	26.70	4.5	4.5	3.30	39.00	17.71
8-3	26.46	4.5	4.5	-	35.46	16.10

Table 4.2-12. Frame Weights at X_o 1187

Support Arrangement	Weights					Totals	
	Frame	Δ For Stiffness	Δ at Z_1 Support	Δ at Z_2 Support	Δ at Y Support	lb	kg
1-2	31.35	-	5.0	4.1	2.2	42.65	19.36
2-2	21.70	-	3.7	3.7	2.2	40.70	18.48
3-2	31.35	-	5.0	4.1	2.2	42.65	19.36
4-2	25.60	-	4.8	4.8	2.1	37.30	16.93
5-2	22.71	-	3.8	3.8	2.2	32.51	14.76
7-2	30.85	2.64	6.95	-	-	40.44	18.36
8-2	22.71	-	3.8	3.8	2.2	32.51	14.76
6-2						42.65	19.36

Table 4.2-13. Support Fitting Weights

Type	NASA Baseline	Convair STSS
X only	?	21.6
Y only	10.0	21.8
Z only	20.0	21.8
Combined X/Z	?	43.2

loads across the Tug/adapter interface. The companion longerons on the support adapter were sized during the adapter preliminary design and are discussed in Section 4.2.3.5.

Weight allocations for the Tug longeron installations were based on the following assumptions:

a. Cross-section areas at loaded end and opposite end are the same as on the adapter and the area varies linearly between the ends.

b. End pads are the same as on the adapter.

c. Longerons extend forward from X_0 1172.9 to X_0 1127.

d. Tug sandwich sidewall is "panned" under longerons (reference Figure 4.2-6).

e. Docking guides (configuration TBD) are integral with longerons and add 0.5 lb (0.23 kg) per longeron.

f. A frame is used at X_0 1128. If a major frame is already there, it was used; if not, a light frame was added (same as the adapter stability frame).

g. Allowed 10 percent on longeron weights for fillet and tolerances.

The resulting weight allowance for the complete longeron installation (excluding any added frame at X_0 1128) was 50.1 lb (22.7 kg).

RMS Fitting. The study of candidate RMS attachment locations resulted in the choice of a single fitting located at X_0 1140 on the Tug sidewall at Y_0 -94; Z_0 400, as shown in Figure 4.2-32. Since this fitting is Tug-mounted no weight difference occurs as a

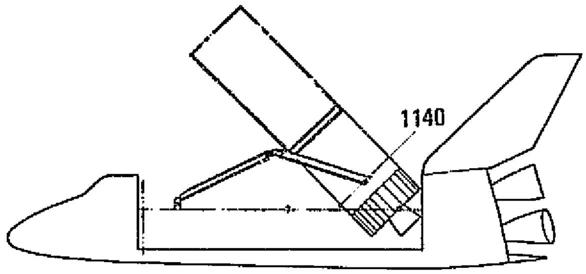


Figure 4.2-32. RMS Fitting Location

function of support arrangement. The RMS fitting was therefore deleted from further consideration in the weight/performance evaluations.

Orbiter Retained (Non-Tug) Items. The non-Tug items consist of the support/deployment adapter structure and mechanisms, the Orbiter bridge beams (in excess of the three sidewall beams and one keel fitting supplied by the Orbiter), the hydraulic load-balancing system(s), and any configuration-dependent subsystems support structure.

Adapter. The support adapter details are presented in Section 4.2.3.5. Among those support arrangements using an adapter, the mechanism weights are constant, and the structure weights vary only as a function of the number of Y and Z support reactions at the aft end. Table 4.2-14 summarizes the adapter weights as a function of support arrangement family.

Table 4.2-14. Adapter Weight Summary

Arrangement Family	Aft Supports		Weights		Total	
	Y	Z	Structure	Mechanisms	lb	kg
6	0	0	497.4	291.0	788.4	357.9
7	1	1	571.9	291.0	862.9	391.8
All others	1	2	593.7	291.0	884.7	401.7

Orbiter Bridge Beams. The configurations and weights of the various Orbiter sidewall and keel support fittings were based on data supplied by Rockwell International. Configurations were given by RI layouts VL 70-004166 (sidewall beams) and VL 70-004167 (keel fittings). Weights were based on the then current RI allocations and are shown in Table 4.2-15.

The net chargeable bridge beam weight for each support arrangement was based on the unit weights of Table 4.2-14 applied to the beam quantities required as given in Table 4.2-16, less those provided by the Orbiter (three sidewall and one keel).

Table 4.2-15. Orbiter Bridge Beam Weights

	Unit Weights		Total	
Location	Fitting	Mechanism	lb	kg
Sidewall	124.0	15.0	139.0	63.1
Keel	78.0	0	78.0	35.4

Load Balancing Systems. Load balancing systems provide a means of reducing support reactions by introducing symmetrical supports without adding redundancy. Later in the study when Orbiter relative deflection data was available, a comparison of redundant and load-balanced concepts was conducted and is discussed in Section 4.2.3.9.

The load balancing system concept as discussed briefly in Section 4.2.2.1 and illustrated in Figure 4.2-16, provides a means of decoupling antisymmetric load components from a selected pair of supports. In the case of the Tug it consists of floating two like supports (two Xs, two forward Zs, or two aft Zs) on an incompressible fluid. The cylinders that provide "float" are plumbed in such a manner that symmetric loads on the support pair (Tug axial inertia on the Xs for example) are reacted from Tug to cylinder to fluid to Orbiter. Antisymmetric loads (yaw bending in support families 3, 4, and 5 for example) are not reacted since the cylinder pistons are free to move in opposite directions on opposite sides of the cargo bay. Yaw bending is then reacted by the dual Y supports without rendering the support system redundant.

Table 4.2-16. Total Required Bridge Beam Quantities

Support Arrangement													
Type	6-1, -2	1-1, -2	7-1, -2	2-1 -2	2-3	8-1 -2	8-3	3-1, -2	3-3	4-1, -2	4-3	5-1, -2	5-3
Side	5	3	4	4	6	4	6	3	5	4	6	4	6
Keel	1	1	1	1	1	1	1	2	2	2	2	2	2

Of the 21 support arrangements candidates, fifteen use at least one load balancing system. Of these, six (families 4 and 5) were doubly balanced (X and Z).

To obtain an estimate of total system weight all identifiable elements in the schematic system were included. To do this, the balancing system configuration variations as a function of support system configuration were investigated. Five different balance system concepts were required to satisfy the 15 support arrangements.

Because of variation in support station between arrangements, the extent of the modification of the current bridge beams to incorporate the balance system installations also varied. Delta weights to bridge beams were estimated, and an example of the modification at X_o 951 was illustrated in Figure 4.2-16. Furthermore, since the magnitudes of support reactions to be carried by the cylinders varied, the cylinder configuration, quantity and unit weight differed.

Cylinders were sized for nominal 3000 psi (20.7 MPa) preload and 6000 psi (41.3 MPa) burst. Radial deflection was found to be excessive in strength designs, so initial wall thicknesses were increased as necessary to limit deflections, and cylinder weights were based on the revised designs.

Plumbing weights were based on CRES tubing (two lines per system) routed along the Orbiter frame nearest the cylinders in question, plus a 25 percent length allowance for local bends, etc.

Accumulators were sized using the same criteria as for the cylinders, assuming a fluid volume of 25 percent of total system volume. Miscellaneous system elements were also estimated.

Weights were accumulated for each affected support arrangement, as illustrated in Figure 4.2-33 and the resulting totals are as shown.

Subsystem Support Structure. For those deploy concepts without a load-carrying adapter, an Orbiter-mounted support structure was required to perform the following functions.

a. Support non-Tug subsystem items located in the cargo bay (avionics packages, helium bottles for abort dump, purge, tank repressurization).

b. Support the active side of the Tug/Orbiter umbilical panels and their associated mechanisms.

c. Provide rotation aid.

The configuration of this element was highly dependent on the number and location of the major subsystem elements (and the plumbing/wiring associated with them), as well as on the deploy concept. Since weight differences as a function of specific configuration were not expected to be large, a weight of 125 lb (57 kg) was assumed for all configurations.

Item	2-1
BRIDGE BEAM Δ	
X (2)	-
Z (2)	20.0
X/Z (2)	-
HYDRAULIC SYSTEM	
Cylinders	
X Tandem	-
Z Single	47.2
Z Tandem	-
Accumulators	
X (2)	-
Z (2)	16.0
Fittings, etc.	
Hydraulic Fill Gas Charge	1.2
Filters	0.8
Check Valves	1.2
Transducers	0.8
Plumbing	9.2
Fluid	10.3
Brackets, etc.	5.0
Σ	111.7

Support Arrangement	Total Weight	
	lb	kg
2-1	111.7	50.7
-2	111.7	50.7
-3	111.7	50.7
3-1	207.1	94.0
-2	207.1	94.0
-3	207.1	94.0
4-1	313.8	142.5
-2	313.8	142.5
-3	313.8	142.5
5-1	385.2	174.9
-2	385.2	174.9
-3	269.2	167.6
8-1	183.1	83.1
-2	183.1	83.1
-3	167.1	75.9

Figure 4.2-33. Load Balancing System Weights

Summary. Weights were computed as discussed above and accumulated in the format illustrated in Figure 4.2-21 for the 21 support arrangements. Arrangement 6-1 was then selected as a baseline (i.e., $\Delta W \equiv 0$), and the Δ weights of all other arrangements were calculated relative to the baseline. The performance partials given in Figure 4.2-21 for synchronous deployment and retrieval missions were then applied to the relative Δ weights to determine the relative Δ performance of each arrangement. The resulting Δ-weight and Δ-performance data is summarized in Table 4.2-17.

4.2.2.4 Selection. Selection of the recommended support arrangements was based on evaluation of the 21 candidates defined in Section 4.2.2.1 with respect to several criteria. In addition to the support reaction evaluation (Section 4.2.2.2) and weight/performance evaluation (Section 4.2.2.3), candidates were also evaluated qualitatively in terms of cost, reliability, and dynamic response. The complete evaluation matrix and the resulting configuration selections are shown in Figure 4.2-34. The reaction exceedance and weight performance data were taken from summaries in the appropriate sections noted above. The cost/reliability evaluation indicated that those arrangements without a support adapter (all -2 options) should be less expensive (due to elimination of the adapter structure and the associated mechanisms) and should experience a slight increase in reliability (again due to mechanism elimination).

The dynamic response evaluation indicated that all redundant (or load-balanced) arrangements were expected to be considerably stiffer than the determinate arrangements. Since the cargo dynamic response portion of the MSFC 68M00039-1 accelerations was more severe in the pitch plane in the critical flight condition (launch release), arrangements with pitch-plane support symmetry (four Z-supports) were ranked better than arrangements with dual-Y supports only (family 3).

The four recommended configurations exhibit the following features:

1-1 Determinate; uses a deployment adapter, penalized by high support reactions, but has the best payload performance.

1-2 Determinate; has no adapter, medium reactions and has the best performance of any adapterless (-2) configuration.

2-1 Singly load balanced (forward Z); has a deployment adapter, shows low reactions and high performance.

2-2 Singly load balanced (forward Z); without adapter, has low support reactions and medium performance.

Table 4.2-17. Weight/Performance Evaluation Summary

Support Option	Location						Δ Weight			Δ Payload					
	Tug			Non-Tug						Deploy			Retrieve		
	Δ W (lb)	Δ PL (lb) Dep	Δ PL (lb) Ret	Δ W (lb)	Δ PL (lb) Dept	Ret	lb	kg	Rank	lb	kg	Rank	lb	kg	Rank
1-1	-111	+292	+154	-182	+ 69	0	-293	-133	8	+361	+164	1	+154	+ 70	2
1-2	+ 92	-242	-127	-941	+358	0	-849	-385	1	+116	+ 53	6	-127	- 58	15
2-1	-116	+303	+159	+ 69	- 26	0	- 47	- 21	11	+277	+126	2	+159	+ 72	1
2-2	+ 75	-195	-103	-691	+263	0	-616	-280	3	+ 68	+ 31	8	-103	- 47	14
2-3	- 12	+ 32	+ 17	+251	- 95	0	+239	+109	15	- 63	- 29	14	+ 17	+ 8	8
3-1	- 90	+236	+124	+103	- 39	0	+ 13	+ 6	13	+197	+ 89	3	+124	+ 56	4
3-2	+114	-299	-158	-656	+249	0	-541	-246	4	- 50	- 23	13	-158	- 72	20
3-3	+ 23	- 62	- 32	+285	-108	0	+308	+140	18	-170	- 77	18	- 32	- 15	13
4-1	- 92	+241	+127	+349	-133	0	+257	+117	16	+108	+ 49	6	+127	+ 58	3
4-2	+103	-270	-142	-411	+156	0	-308	-140	7	-114	- 52	17	-142	- 64	17
4-3	+ 11	- 28	- 15	+531	-202	0	+542	+246	20	-230	-104	20	- 15	- 7	12
5-1	- 77	+202	+106	+420	-160	0	+343	+156	19	+ 42	+ 19	9	+106	+ 48	5
5-2	+114	-297	-157	-339	+129	0	-225	-102	9	-168	- 76	18	-157	- 71	19
5-3	+ 9	- 23	- 12	+586	-223	0	+595	+270	21	-246	-112	21	- 12	- 5	11
6-1	0	0	0	0	0	0	0	0	12	0	0	11	0	0	10
6-2	+124	-326	-172	-663	+252	0	-539	-245	5	- 74	- 34	15	-172	- 78	21
7-1	- 54	+142	+ 75	- 65	+ 25	0	-119	- 54	10	+167	+ 76	4	+ 75	+ 34	7
7-2	+108	-282	-149	-802	+305	0	-694	-315	2	+ 23	+ 10	10	-14.9	- 68	18
8-1	- 68	+178	+ 94	+140	- 53	0	+ 72	+ 33	14	+125	+ 57	5	+ 94	+ 43	6
8-2	+ 99	-259	-136	-619	+235	0	-520	-236	6	- 24	- 11	12	-136	62	16
8-3	- 9	+ 23	+ 12	+306	-116	0	+297	+135	17	- 93	- 42	16	+ 12	+ 5	9

EVALUATION

CONFIG		EXCEEDANCE		QUANTITATIVE CRITERIA		QUALITATIVE CRITERIA		SELECT
NO.	REDUNDANCY	MSFC Σ	JSC Σ	ΔWT	ΔPL	COST & RELIAB	DYNAMIC RESPONSE	
1-1	0	344.9	218.1	-293	+361	0	0	X
1-2		243.4	41.6	-842	+108	+	0	X
2-1	1	193.4	184.8	-47	+277	0	++	X
2-2		213.0	29.2	-609	+59	+	++	X
2-3		287.6	143.8	+239	-63	0	++	
3-1	1	341.5	17.3	+13	+197	0	+	
3-2		282.4	16.5	-535	-58	+	+	
3-3		409.5	121.3	+308	-170	0	+	
4-1	2	266.0	0	+257	+108	0	++	
4-2		239.0	0	-300	-122	+	++	
4-3		266.4	92.4	+542	-230	0	++	
5-1	2	250.6	14.6	+343	+42	0	++	
5-2		184.0	3.2	-219	-177	+	++	
5-3		242.6	8.2	+595	-246	0	++	
6-1	0	430.7	172.7	0	0	0	0	
6-2		365.7	125.7	-532	-83	+	0	
7-1	0	578.0	242.9	-119	+167	0	0	
7-2		617.2	250.9	-688	+14	+	0	
8-1	1	338.6	229.7	+72	+125	0	++	
8-2		256.0	160.6	-514	-32	+	++	
8-3		317.4	130.6	+297	-93	0	++	

(1) 0 = NOMINAL; + = IMPROVEMENT

RECOMMENDED CONFIGURATIONS

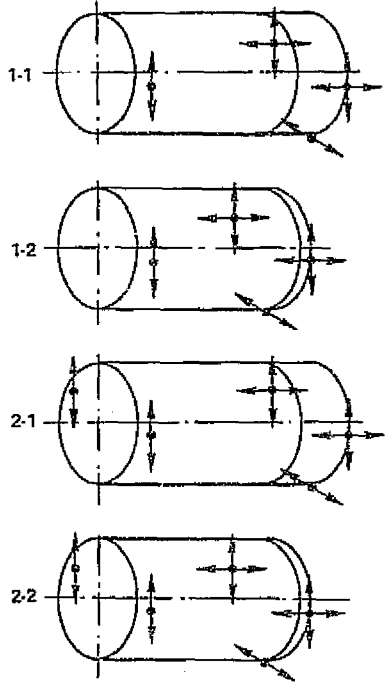


Figure 4.2-34. Support Arrangement Evaluation and Selection

The following rationale was used for selection of the recommended arrangements:

a. Load balancing of X-supports is heavy (207 lb, (94 kg)) and complicated for the amount of reaction reduction achieved (151.9 × 10^3 lb (68.9 × 10^3 kg) maximum to 127.6 × 10^3 lb (57.8 × 10^3 kg), which still exceeds Orbiter capability). It is probably better to revise the Orbiter longerons.

b. Load balancing of Z-supports is also heavy — 112 lb (51 kg) and complicated but reduces reactions substantially and provides a reduction in dynamic response by providing symmetry and eliminating torsion.

c. Forward Z balancing (families 2, 4) is better than aft Z balancing (families 5, 8) in terms of reactions, weight, and performance.

d. From a, b, c: Eliminated families 5 and 8 and considered eliminating families 3 and 4.

e. All -3 configurations rank poorly in weight, performance and reactions; therefore eliminated all -3s.

f. All determinate systems (families 1, 6, 7) are poor in reactions except 1-2. Among determinate systems: family 1 is better than 6 or 7 in weight, performance, and reactions. Therefore eliminated families 6, 7.

g. Among singly balanced families (2, 3), family 2 is better in weight, performance, and reactions; also it provides the reduction in dynamic response noted in item b; therefore, eliminated family 3.

h. Comparing families 4 and 2, family 2 is better in weight, performance, and reactions except for 4-2, which is the best system of all for reactions using JSC accelerations. Comparing 4-2 with 2-2, the only difference in reactions (other than in the X direction) is in Y (4-2 is well inside capability, but 2-2 is also within Y capability), so the implied Orbiter impact between the two is limited to item a. Reactions in 2-1 and 2-2 are similar and permit good comparison of with/without adapter concepts. 2-1 has high X reactions but X/Z combinations at Z_{MAX} are within Orbiter capability. Therefore, only X reinforcement is required in the Orbiter, which eliminated 4-1, 4-2.

i. Summary: Retained 1-1, 1-2, 2-1, and 2-2. This permits comparison between determinate and load-balanced systems and further permits an adapter/no-adapter comparison in each system.

4.2.3 <u>DETAILED ASSESSMENT AND SPECIAL EMPHASIS TASKS.</u> The detailed assessment tasks were conducted to expose differences among the four support arrangements recommended in the screening analysis to select a preferred structural interface and define its requirements in detail. A finite element analysis of the Tug and adapter was conducted to 1) validate/update the shell load peaking and frame load dissipation derived in the screening analysis and thus more accurately define the sidewall reinforcement and major framing requirements of the reference vehicle, 2) assess deflections versus the Orbiter cargo bay envelope, and 3) aid in determining stiffnesses for use in the dynamic response analysis.

Support fitting designs were prepared to 1) update the corresponding weight, 2) accommodate the Orbiter trunnion and keel fitting configurations, and 3) accommodate vertical payload changeout at the launch site. In addition, the impact of bearing/shaft friction in the ±Y direction at the Z and X/Z supports was also investigated in response to specific customer request.

The dynamic analysis identified the lower frequencies and their mode shapes for four support arrangements and subsequently investigated the response of one of the arrangements to forcing functions representing the Shuttle liftoff transient.

The special emphasis structures tasks were conducted in response to several items of concern resulting either from problems identified during the detailed assessment tasks

or from changes in requirements. Figure 4.2-35 identifies the areas of concern and the task flow used to address each while converging to selection of a recommended structural support system.

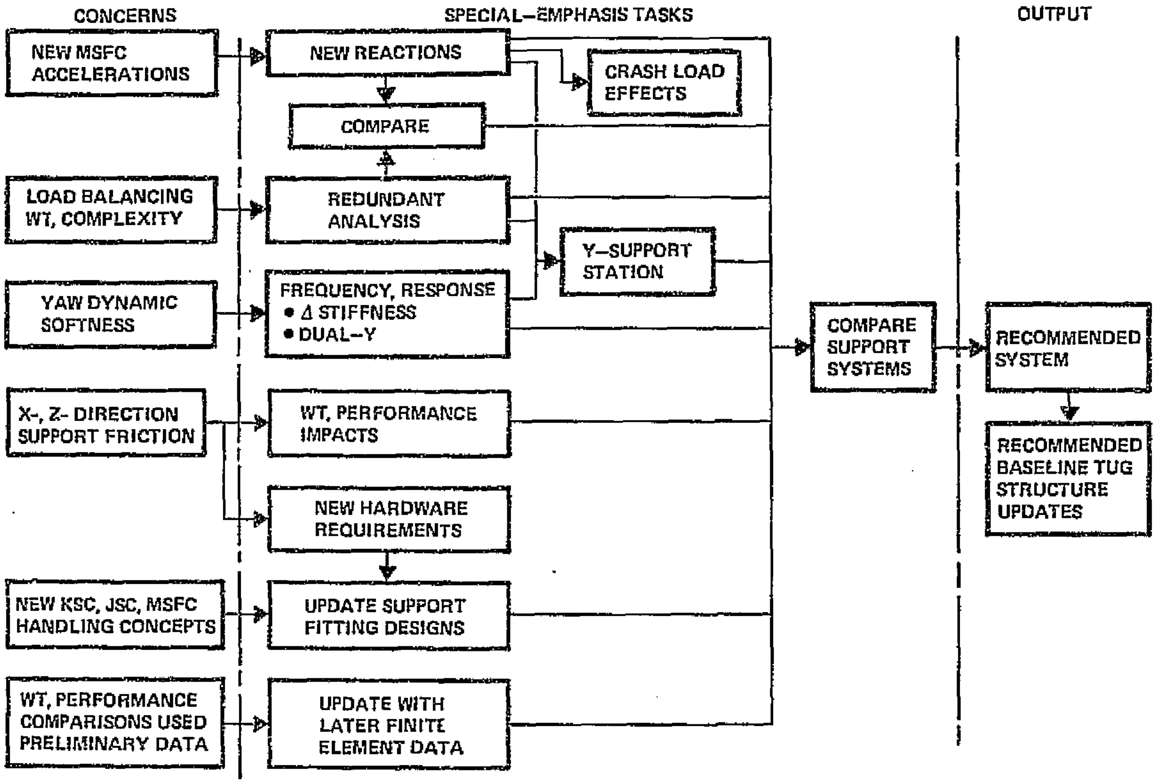


Figure 4.2-35. Special Emphasis Tasks

New support reactions for all flight conditions, including crash, were computed using the latest accelerations per MSFC PF-02-75-31. These were compared with the previous data, and the extent of any exceedance of Orbiter capability was determined. Redundant support systems could not be investigated initially for lack of Orbiter stiffness and/or deflection data. Later, preliminary Orbiter deflection data was received and used to assess the feasibility of redundant support systems in terms of both support reactions and Tug body loads.

Initial dynamic analyses indicated uniformly low first mode frequencies coupled with excessive acceleration and displacement response in the yaw direction. As a result additional modal and forced response analyses were conducted for systems offering increased yaw stiffness. The station location of the Y-support significantly affects reactions and dynamic displacement response in all single-Y systems. Accordingly a study of the effect of Y-support location was conducted using data from the reactions, redundant support, and dynamics tasks.

Initially, only Y-direction friction at Z and X/Z supports was investigated for impacts on Tug weight and performance. This effort was expanded to consider friction forces in both the X and Z direction at all support locations. Weight and performance penalties were determined as were any support fitting impacts due to new hardware requirements. The original Z and X/Z support fittings designs included ground handling provisions that are no longer compatible with the KSC AGE concept. Consequently the original concept was compared with the current KSC, JSC, and MSFC fitting design concepts, and updated support fitting designs were prepared.

During the preliminary screening analysis 21 support systems were evaluated in several categories including weight and performance. At that time only preliminary weight data was available. Detailed finite element analyses were later conducted, and the resulting load distribution and deflection data were used to more accurately identify Tug weight impacts and the resulting performance differences between candidate support systems. Candidate support systems were then compared on the basis of weight, performance, support reactions, and dynamic response and a recommended Tug structural support system was selected.

4.2.3.1 Finite Element Analysis. One of the major structural tasks performed during the Tug interface study was a finite element computer analysis of the complete Tug/deployment adapter structure.

Objectives. Tug structural weight was one of the major parameters used in the preliminary screening of alternative support concepts. For the preliminary screening analysis, Tug structure weight was estimated from simple sizing relationship based on data extracted from the Tug finite element model generated during the Convair STS study. One of the significant points developed during the earlier STS study was that the internal loading distribution in the Tug does not correspond to conventional engineering beam theory. Because the Tug body is a short, large-diameter shell that is point loaded, internal axial and shear loading is highly peaked.

Internal loads and member sizes thus cannot be estimated accurately using conventional theory. Since there are significant differences between the STSS Tug and the current baseline Tug configurations, it was difficult to assess the accuracy of applying STSS data to the current configuration. Therefore, one of the primary objectives of the Tug finite element analysis was to validate the methods used to size major Tug support frames and body shell reinforcement in the preliminary screening of alternative support concepts.

Tug and payload deflections and clearance loss were identified as potentially significant screening criteria for alternative support concepts. However, because accurate stiffness models of the various Tug configurations were not available during the

preliminary screening assessment deflections and clearance loss could be evaluated only in a qualitative manner. A second major objective of the Tug finite element analysis was thus to evaluate Tug and payload deflections and loss of clearance for those support configurations selected for detailed assessment.

To obtain accurate relative weight information, it was necessary to size many of the major Tug structural elements. This provided a means for updating the baseline Tug structure. The third objective of the Tug finite element analysis was therefore to further update the baseline Tug by resizing major structural elements as required for strength and stiffness compatibility.

Changing requirements during future Tug studies may require modification to the baseline Tug and its support configuration. A fourth objective of the Tug finite element analysis was to create a versatile Tug model that could be easily modified to accommodate all candidate support configurations, permit selective loading, and provide flexibility for future use.

Methodology. The baseline four-point (single eccentric forward Z) and the five-point (load-balanced dual forward Z) support concepts were selected, as a result of the preliminary screening analysis, for further detailed assessment. To permit more detailed evaluation it was decided that, rather than try to evaluate all the candidate support configurations, only these two configurations could be evaluated initially using the finite element model.

An existing Convair structural analysis program (SOLID SAP) was used to perform the Tug finite element analysis. SOLID SAP is a large capacity computer program for the linear elastic analysis of three-dimensional structural systems. The structural systems to be analyzed may be composed of combinations of any of the structural element types:

a. Three-dimensional truss.

b. Three-dimensional beam.

c. Plane stress and plane strain.

d. Two-dimensional axisymmetric solid.

e. Three-dimensional solid.

f. Plate and shell.

g. Boundary.

h. Thick shell element.

The size of the structural system is not inherently limited and is restricted in practice only by considerations of time and cost. While the solution scheme is bandwidth oriented there is no restriction (save cost) on the size of the bandwidth. However, there is an internal module that can be used to internally resequence the grid points to reduce the bandwidth. The program is coded in standard Fortran IV and is operational on the Convair CDC Cyber 70 computer.

The Tug finite element model (shown schematically in Figure 4.2-35A) is a full 360-degree model that can accommodate both unsymmetric Tug geometry and loading. The

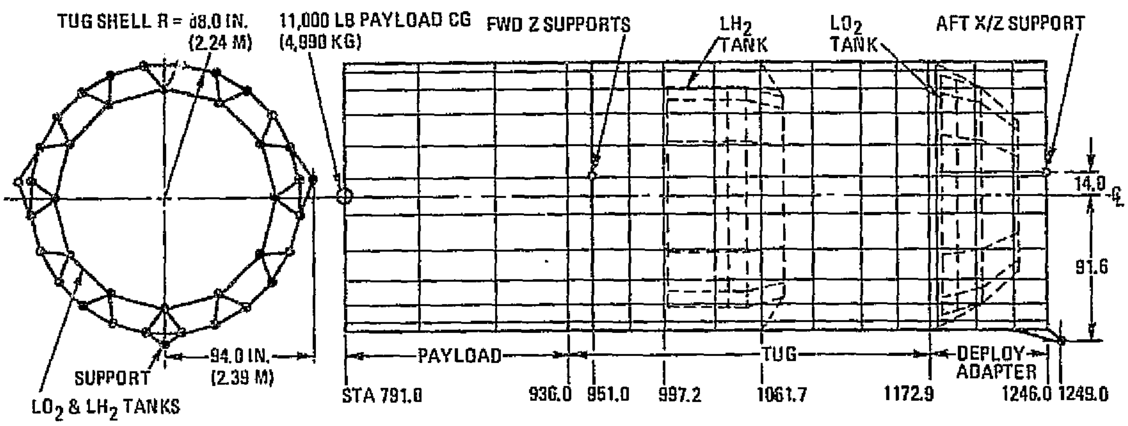


Figure 4.2-35A. Tug Finite Element Model

model includes a 176-inch (440 cm) diameter shell representing the payload, Tug structural shell, and deployment adapter. The shell grid consists of 15-degree circumferential increments (23 inches; 57.5 cm) with longitudinal grid spacing varying from a minimum of 15 inches (37.5 cm) at the forward end of the Tug to a maximum of 48 inches (120.0 cm) in the payload area.

LO_2 and LH_2 inertia loads were introduced into the Tug shell by axial truss elements representing the tank support struts. The LO_2 tank model used 24 struts (in pairs), and the LH_2 tank model used 12 struts (in pairs). In addition the LH_2 tank model incorporated a forward lateral support consisting of six tangential struts between the tank and shell at Station 997.2. The tanks were represented by truncated shell structures, which permitted introduction of propellant inertia loads at the CG of each tank. The Tug structural shell was attached to the deploy adapter model by means of 14 short stiff beam elements to approximate the 11 latches. Support fittings were modeled as combinations of truss and beam elements. The model was generated with five support points with an option of either using or not using the second forward Z

fitting so that both the load balanced 5-point (2-1) and baseline 4-point (1-1) configurations could be evaluated using the same basic model.

Results of the preliminary screening analysis were used to estimate initial member sizing. After the initial computer run, member sizes were updated to eliminate areas of obvious overstress. The major frames at Stations 951.0, 997.2, 1061.7, 1172.9, and 1246.0 were all sized using criteria established for the initial screening analysis. Frames were modeled as beams with their centroid offset from the shell.

The graphite epoxy sandwich used for the Tug structural shell was represented as pseudo-isotropic membrane panels in the model. Because of the wide variation in possible ply layups, it was decided that pseudo isotropic properties would best fit our requirements for these early analyses. It should be noted that, in the future, the model can be modified to include orthotropic properties for the structure. A basic effective thickness of 0.027 inch (0.07 cm) with a modulus $E = 16 \times 10^6$ psi (11×10^6 N/cm^2) was used.

Two unit case runs were made. The first preliminary run was used to check out the model and provide data to ensure member sizes were reasonable. The second run incorporating updated member properties and geometry was used for final member sizing and deflection analysis. The finite element analysis was performed using the initial set of MSFC 68M00039-1 load factors provided at the start of the study. Late in the study (after the finite element analysis was essentially complete) a new set of load factors (MSFC PF02-75-31) was supplied to replace the earlier values. Schedule and budget constraints prohibited the incorporation of these new load factors in the finite element analysis. Load factors used in the finite element analysis are summarized in Table 4.2-17A. In general, these load factors are much more conservative than the later MSFC PF02-75-31 values.

Unless otherwise noted all finite element results presented reflect the load factors in Table 4.2-17A. During the Weight/Performance Evaluation Update (Section 4.2.3.10) some of the finite element analysis results were modified to reflect the latest load factors. In general, this was accomplished by reducing the internal loads by the ratios of appropriate load factors and resulting support reactions. Tug missions analyzed and the mass properties assumed for each mission phase in the finite element analysis are summarized in Table 4.2-17B.

For the descent mission phase, the finite element analysis configuration was based on the original study ground rule of no LH_2 dump before abort descent. This ground rule had changed late in the study to dump both LO_2 and LH_2 before abort descent. Schedule constraints did not permit rerunning the finite element analysis without LH_2 for the abort descent loading conditions. Since most of the Tug structure was critical for ascent loading conditions, this change in ground rules did not significantly impact the finite element analysis conclusions.

Table 4.2-17A. Load Factors Used for Finite Element Analysis

Cond No.	Mission Phase	Load Condition	MSFC 68M00039-1 a_x Max	a_x Min	a_y Max	a_y Min	a_z Max	a_z Min
A1	Ascent(1)	Liftoff						
A2		Thrust Buildup/ Rebound	-0.5	-1.5	+0.3	-0.3	+0.3	-0.3
		Launch Release	+0.4	-3.4	+0.8	-0.8	+3.0	-3.0
A3		Hi-Q Boost	-1.7	-2.3	+0.9	-0.9	+1.1	-1.1
A4		Max G with SRMs	-2.7	-3.3	+0.5	-0.5	+0.6	-0.6
A5		SRM Cutoff/ Separation	+2.0	-4.0	+0.4	-0.4	+0.8	-0.8
A6		Max Orbiter Only	-2.7	-3.3	+0.3	-0.3	-0.4	-0.3
A7		Orbiter Cutoff/ Separation	+1.9	-2.1	+0.4	-0.4	+0.6	-0.2
O1	On-Orbit(1)	Payload Deployment	+0.2	-0.2	+0.2	-0.2	+0.2	-0.2
D1	Descent(1)	Entry	+1.4	+0.6	+0.7	-0.7	+4.0	+2.0
D2		Flyback	+0.6	-0.6	+0.3	-0.3	+1.4	+0.6
D3		Landing	+1.3	+0.7	+0.3	-0.3	+3.0	+1.0

Table 4.2-17B. Tug Mass Properties Used for Finite Element Analysis

Mission	Phase	Payload		Body and Deploy Adapter		LH_2 Tank*		LO_2 Tank**		Total	
		Wt lb/(kg)	CG Sta	Wt lb/(kg)	CG Sta	Wt lb/(kg)	CG Sta	Wt lb/(kg)	CG Sta	Wt lb/(kg)	CG Sta
Deploy	Ascent	11,000 (4990)	791.0	4672 (2119)	1093.3	7820 (3547	1037.2	40,316 (18,287)	1179.6	63,808 (28,943)	1088.8
	Descent	11,000 (4990)	791.0	4672 (2119)	1093.3	7820 (3547)	1037.2	1131 (513)	1214.6	24,623 (11,169)	946.0
Retrieve	Ascent	0	-	4672 (2119)	1093.3	8488 (3850)	1031.7	44,330 (20,108)	1175.5	57,490 (26,077)	1147.6

*Includes tank and propellants.
**Includes tank, engine, and propellants.

Results. Critical deflections and major frame, body shell, tank support start, and latch loads were extracted from the computer output and are ımmarized below.

Shear, axial load, and bending moments in the forward Z support frame at station 951 are shown in Figure 4.2-35B for both the baseline four-point (1-1) and five-point load balanced forward Z (2-1) configurations. Load condition A2 (liftoff launch release) from Table 4.2-17A produces maximum loading in the frame. As shown, the use of dual forward Z supports significantly reduces peak loads in the station frame.

Shear, axial load, and bending moments in the aft Y/Z support frame at station 1246 are shown in Figure 4.2-35C for the baseline four-point (1-1) configuration. Loads for both the maximum Z reaction condition (A2) and the maximum Y reaction condition (A3) from Table 4.2-17A are presented.

Since several loading conditions are critical for different segments of the body shell, it was convenient for Tug shell sizing to develop maximum load envelopes instead of plotting load distributions for individual load conditions. Envelope plots of maximum Tug body shell load intensities (axial load intensity, N_0, and shear flow, q) are presented in Figures 4.2-35D for configuration 1-1 and in Figure 4.2-35E for configuration 2-1.

Maximum loads in the 24 LO_2 tank support struts are presented in Table 4.2-17C for both the baseline (1-1) and dual load balanced forward Z (2-1) configurations. Maximum loads in the LH_2 tank aft 12 support struts are presented in Table 4.2-17D, and the maximum loads in the six forward lateral support struts for the LH_2 tank are presented in Table 4.2-17E.

Discrete latches were represented in the computer model by 14 short beam segment links between the Tug and deploy adapter at the locations shown in Figure 4.2-35F. Maximum latch loads for configurations 1-1 and 2-1 are tabulated in Table 4.2-17F.

The finite element analysis output was used to evaluate critical Tug deflections. One of the major deflection considerations was compatibility of the 176-inch (440 cm)-diameter Tug with the available 180-inch (450 cm)-diameter payload envelope in the Orbiter cargo bay. Tug maximum clearance loss occurs at the forward Z support (station 951). Maximum deflections at station 951 for both configurations 1-1 and 2-1 are shown in Figure 4.2-35G. Condition A2 (Table 4.2-17A) is critical.

For the baseline single forward Z support (configuration 1-1) maximum clearance loss was 6.77 inches (17.20 cm), which indicates the shell would project a maximum of 4.77 inches (12.12 cm) outside the available envelope. Of the total clearance loss, approximately 4.16 inches (10.57 cm) was due to motion of the Tug centerline and 2.61 inches (6.63 cm) was due to local frame deflection. With a dual load balanced forward support (configuration 2-1), the maximum clearance loss for the same loading

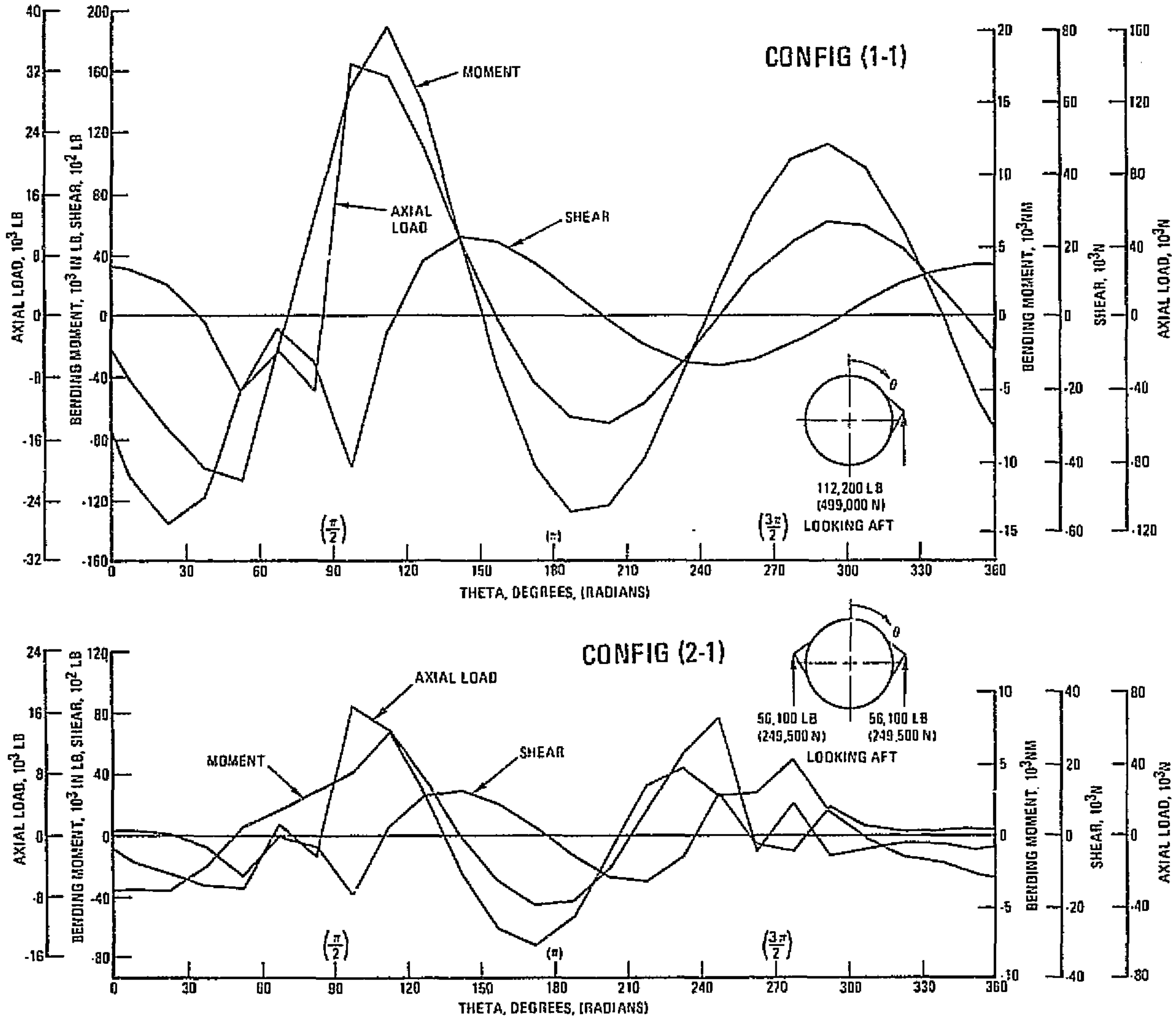


Figure 4.2-35B. Loads in Forward Z Support Frame (Station 951.0)

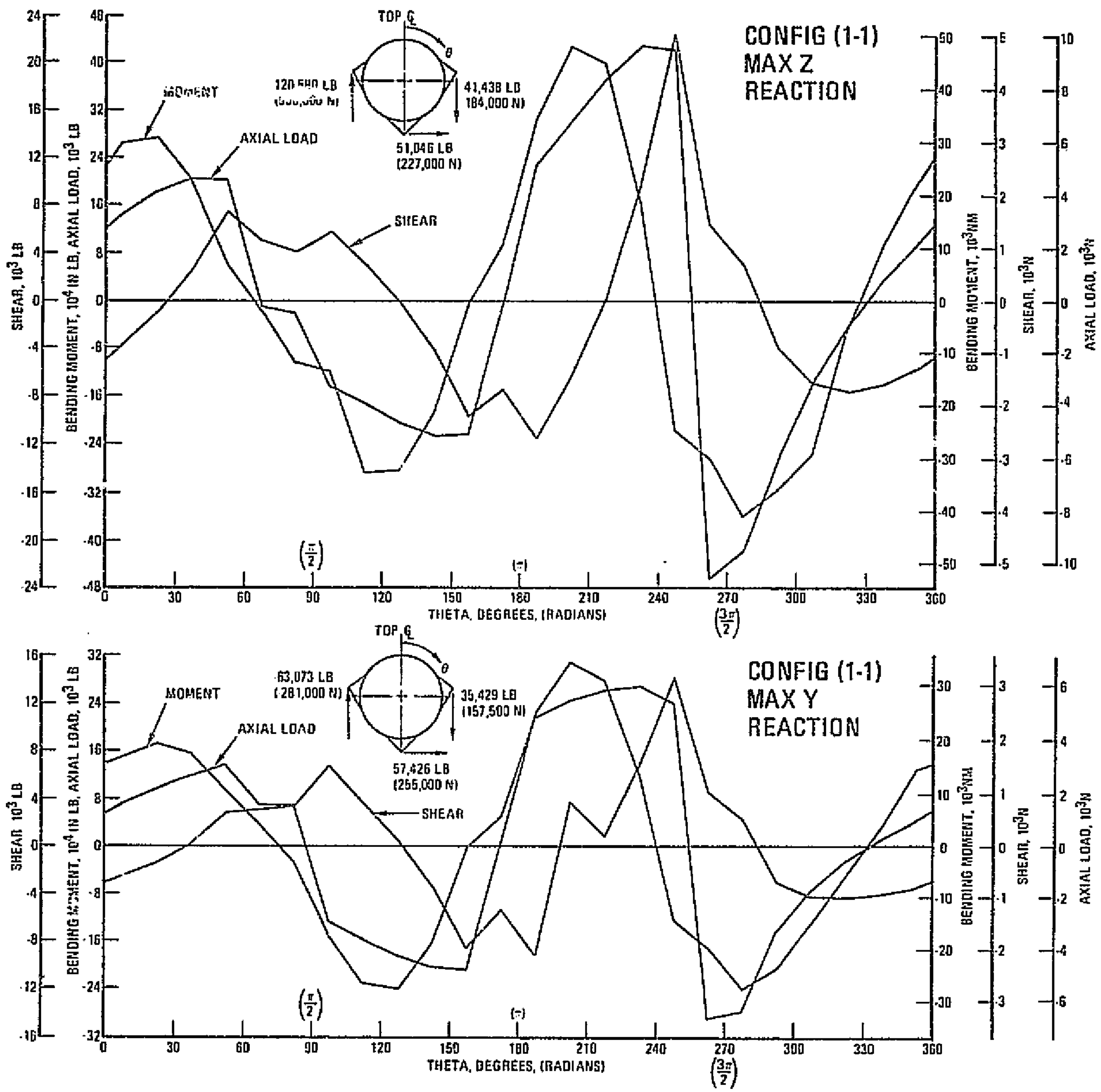


Figure 4.2-35C. Loads in Aft Y/Z Support Frame (Station 1246.0)

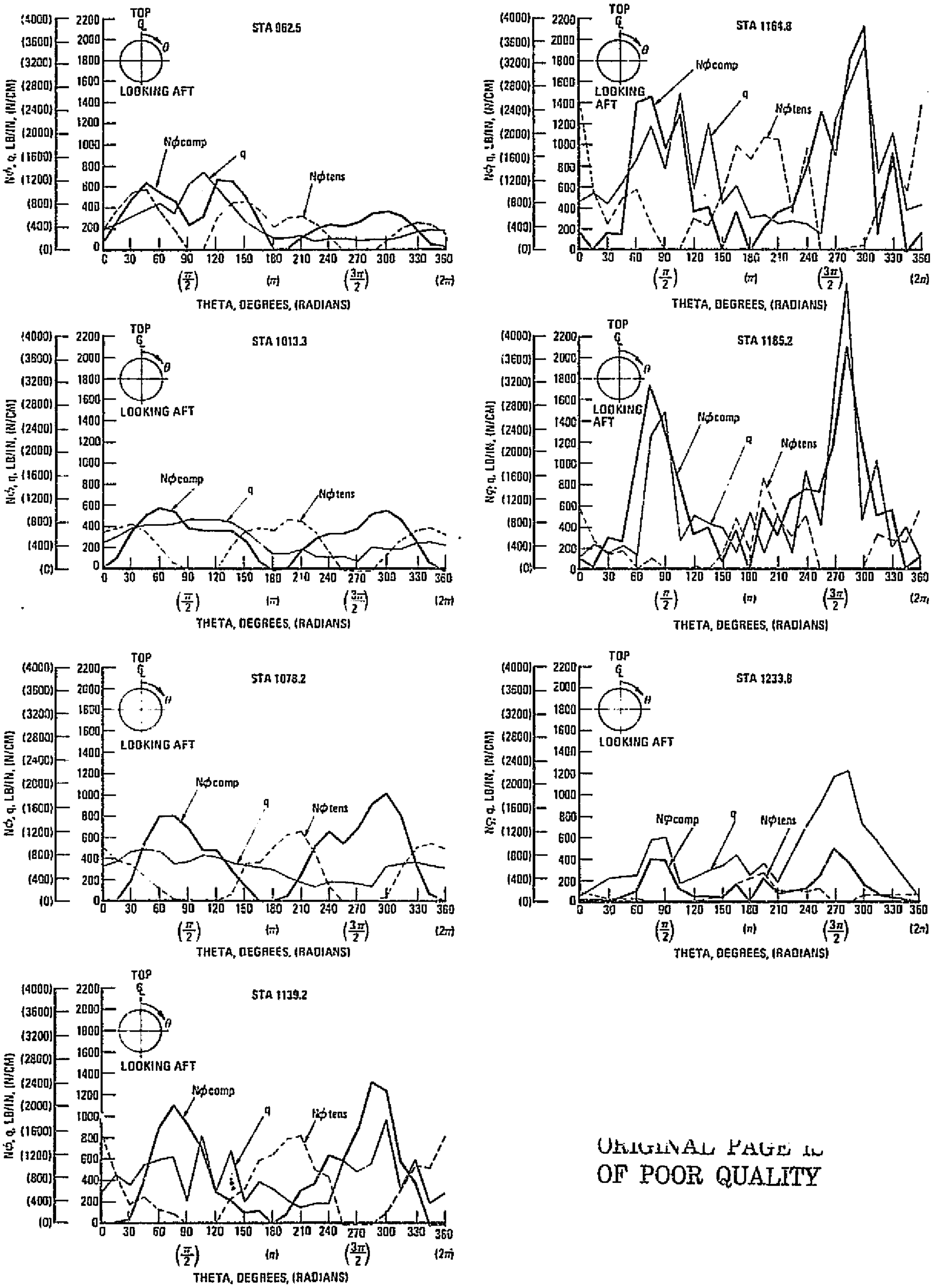


Figure 4.2-35D. Tug Body Load Envelopes (Configuration 1-1)

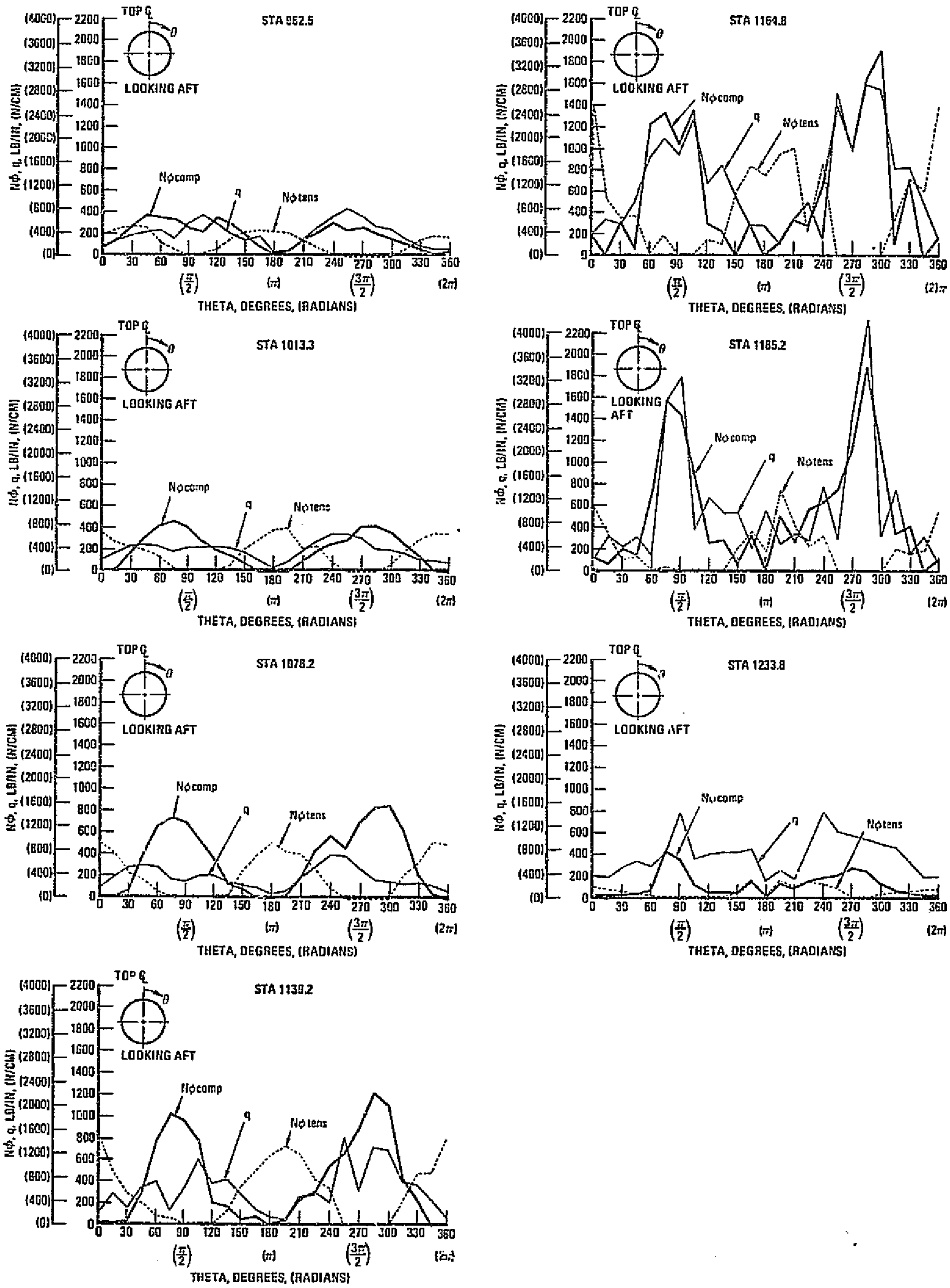


Figure 4.2-35E. Tug Body Load Envelopes (Configuration 2-1)

Table 4.2-17C. Tug LO_2 Tank Maximum Support Strut Loads

Strut	Configuration 1-1				Configuration 2-1			
	Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.	Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.
1	-	-	15208 (67640)	A3/Retrieve	-	-	15963 (71007)	A3/Retrieve
2	- 1356 (- 6032)	A2/Deploy	19297 (85837)	A2/Retrieve	- 507 (- 2255)	A2/Deploy	18678 (83084)	A2/Retrieve
3	-16660 (-74100)	A2/Retrieve	35628 (158481)	A2/Retrieve	-15306 (- 68347)	A2/Retrieve	34694 (154327)	A2/Retrieve
4	-23003 (-102322)	A2/Retrieve	41477 (184499)	A2/Retrieve	-23871 (-106183)	A2/Retrieve	42681 (189854)	A2/Retrieve
5	-34942 (-155430)	A2/Retrieve	52573 (233856)	A2/Retrieve	-35469 (-157774)	A2/Retrieve	52953 (235547)	A2/Retrieve
6	-42716 (-190019)	A2/Retrieve	56569 (251720)	A2/Retrieve	-44119 (-196251)	A2/Retrieve	58531 (260359)	A2/Retrieve
7	-41936 (-319987)	A2/Retrieve	62832 (279491)	A2/Retrieve	-4 .024 (-195828)	A2/Retrieve	64339 (286194)	A2/Retrieve
8	-44291 (-197016)	A2/Retrieve	64873 (288569)	A2/Retrieve	-44839 (-199454)	A2/Retrieve	65633 (291950)	A2/Retrieve
9	-39408 (-175696)	A2/Retrieve	58961 (262771)	A2/Retrieve	-40923 (-182035)	A2/Retrieve	59089 (266844)	A2/Retrieve
10	-34934 (-155394)	A2/Retrieve	56885 (253037)	A2/Retrieve	-34185 (-152062)	A2/Retrieve	53846 (248415)	A2/Retrieve
11	-29883 (-132926)	A2/Retrieve	43865 (195121)	A2/Retrieve	-29249 (-130106)	A2/Retrieve	45407 (193084)	A2/Retrieve
12	-21426 (-95308)	A2/Retrieve	39233 (174517)	A2/Retrieve	-19695 (-87608)	A2/Retrieve	36834 (163846)	A2/Retrieve
13	-16663 (-73676)	A3/Retrieve	23358 (103902)	A2/Deploy	-15636 (-69552)	A3/Retrieve	20928 (93092)	A2/Retrieve
14	- 30 (-133)	A2/Deploy	14232 (63307)	A2/Retrieve	- 1091 (-4853)	A2/Deploy	14688 (65335)	A2/Retrieve
15	- 8633 (-38401)	A2/Retrieve	30006 (133473)	A2/Retrieve	- 9382 (-41733)	A2/Retrieve	31043 (138086)	A2/Retrieve
16	-29972 (-133322)	A2/Retrieve	48646 (216388)	A2/Retrieve	-28546 (-126979)	A2/Retrieve	47618 (211815)	A2/Retrieve
17	-36471 (-162331)	A2/Retrieve	57476 (255666)	A2/Retrieve	-35920 (-159780)	A2/Retrieve	56712 (252267)	A2/Retrieve
18	-49176 (-218740)	A2/Retrieve	68916 (306554)	A2/Retrieve	-47091 (-209471)	A2/Retrieve	67412 (299863)	A2/Retrieve
19	-54801 (-243767)	A2/Retrieve	69747 (310250)	A2/Retrieve	-53401 (-237539)	A2/Retrieve	67807 (301620)	A2/Retrieve
20	-49735 (-221232)	A2/Retrieve	67079 (298383)	A2/Retrieve	-49207 (-218884)	A2/Retrieve	66898 (296087)	A2/Retrieve
21	-47151 (-209738)	A2/Retrieve	66286 (294855)	A2/Retrieve	-46285 (-205886)	A2/Retrieve	65085 (289512)	A2/Retrieve
22	-32033 (-142490)	A2/Retrieve	51715 (230040)	A2/Retrieve	-33323 (-148228)	A2/Retrieve	52646 (234181)	A2/Retrieve
23	-24029 (-106886)	A2/Retrieve	42231 (187853)	A2/Retrieve	-24475 (-108870)	A2/Retrieve	42848 (189699)	A2/Retrieve
24	-11193 (-49789)	A3/Retrieve	25961 (115480)	A2/Retrieve	- 1195 (-5316)	A3/Retrieve	27379 (121798)	A2/Retrieve

Notes: 1. See Table 4.2-17A for load factors.

2. Strut locations are as shown.

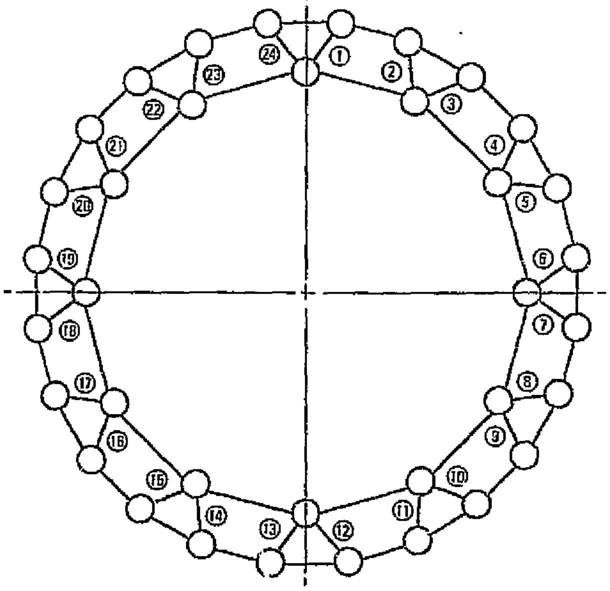


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Table 4.2-17D. Tug LH_2 Tank Maximum Aft Support Strut Loads

Strut	Configuration 1-1 Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.	Configuration 2-1 Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.
1	-464 (-2064)	A2/Deploy	6909 (30733)	A2/Deploy	-	-	4339 (19301)	A2/Retrieve
2	-	-	6247 (27788)	A2/Retrieve	-	-	6383 (28393)	A2/Retrieve
3	-	-	6201 (11570)	A2/Retrieve	-	-	2707 (12041)	A2/Retrieve
4	-149 (-663)	A2/Deploy	4153 (18473)	A2/Retrieve	-238 (-1059)	A2/Deploy	4218 (18763)	A2/Retrieve
5	-	-	7678 (34153)	A2/Retrieve	-	-	7973 (35466)	A2/Deploy
6	-956 (-9252)	A2/Deploy	5979 (26596)	A2/Deploy	-	-	3487 (15511)	A2/Retrieve
7	-	-	4533 (20164)	A2/Deploy	-	-	4025 (17904)	A2/Retrieve
8	-	-	6629 (29487)	A2/Retrieve	-	-	6615 (29425)	A2/Retrieve
9	-	-	2629 (11694)	A2/Retrieve	-	-	2650 (11788)	A2/Retrieve
10	-643 (-2860)	A3/Deploy	4432 (19715)	A2/Retrieve	-522 (-2322)	A3/Deploy	4295 (19105)	A2/Retrieve
11	-	-	7970 (35452)	A2/Deploy	-	-	7537 (33526)	A2/Deploy
12	-	-	5042 (22428)	A2/Deploy	-	-	3676 (16352)	A2/Retrieve

Notes: 1. See Table 4.2-17A for load factors

2. Strut locations are as shown.

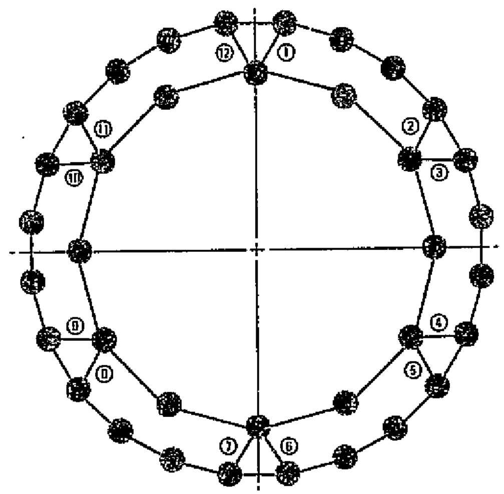
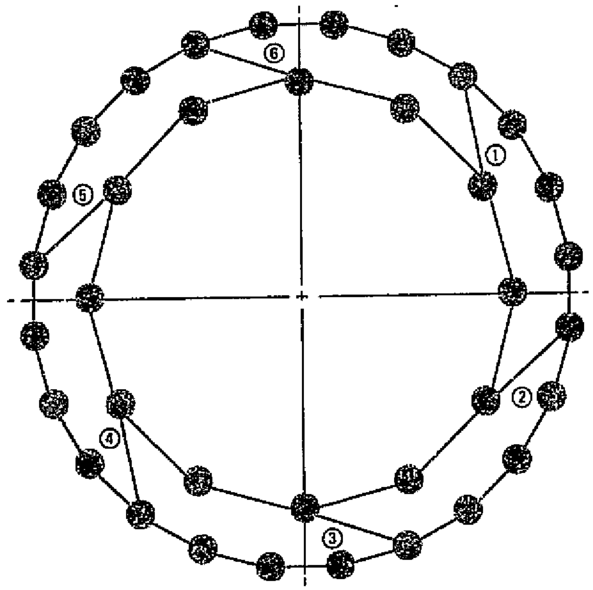


Table 4.2-17E. Tug LH_2 Tank Maximum Forward Support Strut Loads

Strut	Configuration 1-1				Configuration 2-1			
	Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.	Comp. Load, lb (N)	Cond.	Tens. Load, lb (N)	Cond.
1	-4264 (-18967)	A2/Retrieve	4545 (20217)	A2/Deploy	-3782 (-16823)	A2/Retrieve	3829 (17032)	A2/Retrieve
2	-6535 (-29069)	A2/Retrieve	6782 (30168)	A2/Retrieve	-5912 (-26298)	A2/Retrieve	5919 (26329)	A2/Retrieve
3	-2193 (-9755)	A2/Retrieve	2226 (9902)	A2/Retrieve	-1875 (-8340)	A2/Retrieve	1786 (7945)	A2/Retrieve
4	-3215 (-14301)	A2/Retrieve	3142 (13976)	A2/Retrieve	-3956 (-17597)	A2/Retrieve	3676 (16352)	A2/Retrieve
5	-5091 (-22646)	A2/Retrieve	5141 (22868)	A2/Retrieve	-5872 (-26120)	A2/Retrieve	5704 (25373)	A2/Retrieve
6	-1522 (-6770)	A2/Retrieve	1446 (6432)	A2/Retrieve	-2003 (-8910)	A2/Retrieve	1793 (7976)	A2/Retrieve

Notes: 1. See Table 4.2-17A for local factors.

2. Strut locations are as shown.



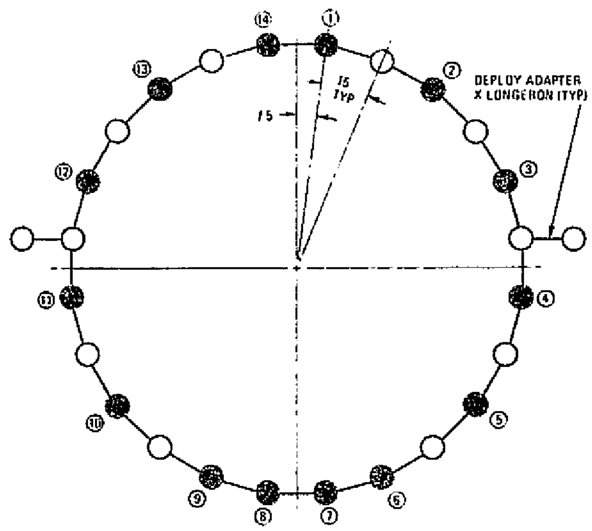


Figure 4.2-35F. Tug Computer Model Latch Locations

condition was only 2.13 inches (5.41 cm), which indicates the shell would project only 0.13 inch (0.33 cm) beyond the available envelope. These results indicate that if some type of dual forward Z support were not used, either relocation of the Y support fitting, a decrease in the Tug diameter, or a significant stiffness increase would be required to maintain the Tug within the available cargo bay payload envelope.

4.2.3.2 Friction at Supports. The initial friction effect investigation was limited to consideration of the Tug weight/performance impact of ±Y-direction friction forces occurring between the Tug fitting shaft and bearing at the support points on the Orbiter sill longeron (Z and X/Z supports). The impact assessment was limited to the NASA baseline arrangement (6-1) and the four selected arrangements. Friction forces were computed using a coefficient of friction of 0.10 applied to the appropriate support reactions on the Tug at X_0 951, 1128, and/or 1187 in the above arrangements. Data from the Convair STSS analysis was used to generate a Tug support frame moment coefficient distribution due to Y direction friction forces, as shown in Figure 4.2-36. Moments (including friction effects based on the coefficient distribution) were then overplotted on existing moment curves. The resulting moment comparisons for the X_0 951 and 1128 frames in arrangement 6-1 are shown in Figure 4.2-37. The friction force increased peak frame moments significantly, but the maximum effect was limited to a relatively small segment of the circumference.

Frame weights, including allowance for friction, were then computed using the methods of Section 4.2.2.3. Table 4.2-18 shows the Tug frame weight comparison, with and without friction allowance, for the five support arrangements investigated. Finally, performance impacts for synchronous deploy and retrieve missions were determined, using these weights and the performance partials previously used in Section 4.2.2.3, and are shown in Table 4.2-19. The subsequent friction investigation was directed both at updating the previous ±Y friction effect data and at assessing the impacts of the following friction forces at various support locations that are nominally "free" in the friction force direction:

a. ±Z Friction at Y Supports. Results either from inflight relative motion due to structural deflection or during programmed motion of the Tug relative to the Orbiter either at ground installation or on-orbit deployment/berthing.

Table 4.2-17F. Tug Separation Latch Maximum Tension Loads

	Configuration 1-1		Configuration 2-1	
Latch	Load, lb (N)	Cond.	Load, lb (N)	Cond.
1	19125 (85072)	A2/Retrieve	20710 (92123)	A2/Retrieve
2	10244 (45568)	A3/Deploy	11676 (51937)	A2/Deploy
3	2694 (11984)	A3/Deploy	-	-
4	-	-	-	-
5	-	-	15100 (67168)	A2/Retrieve
6	7560 (33629)	A2/Deploy	25123 (111753)	A2/Retrieve
7	20867 (92821)	A2/Deploy	20633 (91780)	A2/Deploy
8	24508 (109017)	A2/Deploy	20633 (91780)	A2/Deploy
9	30326 (134897)	A2/Deploy	25123 (111753)	A2/Retrieve
10	21038 (93582)	A2/Retrieve	15100 (67168)	A2/Retrieve
11	-	-	-	-
12	-	-	-	-
13	19296 (85833)	A2/Deploy	11676 (51937)	A2/Deploy
14	19094 (84934)	A2/Deploy	20710 (92123)	A2/Retrieve

Notes: 1. See Table 4.2-17A for load factors.

2. See Figure 4.2-35F for latch locations.

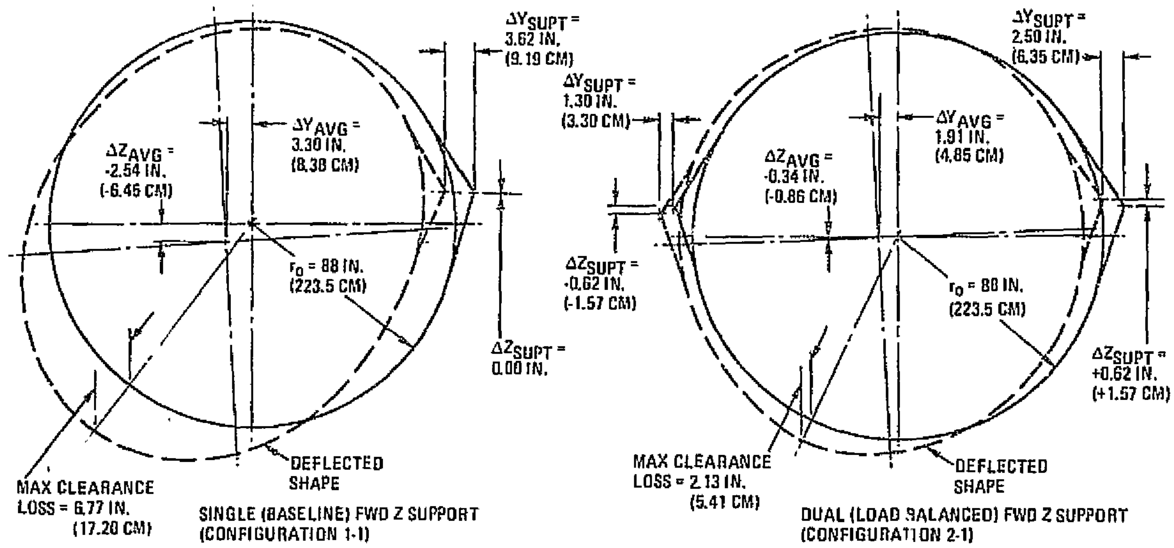


Figure 4.2-35G. Tug Shell Envelope at Forward Z Support (Station 951)

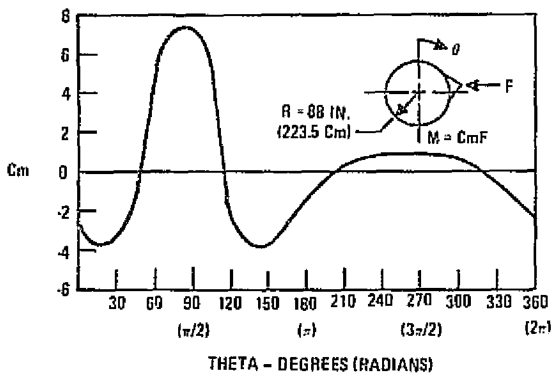


Figure 4.2-36. Frame Moment Coefficient for Radial Friction Load

b. <u>±X Friction at Z-Only Supports.</u> Arises from the motion of the Orbiter trunnion in guides provided in the supporting bridge beam.

c. <u>±X Friction at Y Supports.</u> Causes are the same as a.

To aid the friction assessment, the finite element analysis included load conditions consisting solely of unit ±Y friction forces at Z and X/Z supports and of unit ±Z friction forces at Y supports. Figure 4.2-38 shows the resulting frame loads at two selected frame locations for support arrangement 1-1. Since frame sizing is largely controlled by bending moments, moments including friction effects were again overplotted on existing moment curves to determine the relative effect of friction. The upper half of Figure 4.2-39 illustrates the source and orientation of the friction forces that lie in-plane with the support frames. The resulting moment comparisons are also shown, and a relatively small moment increase due to friction is indicated in both cases.

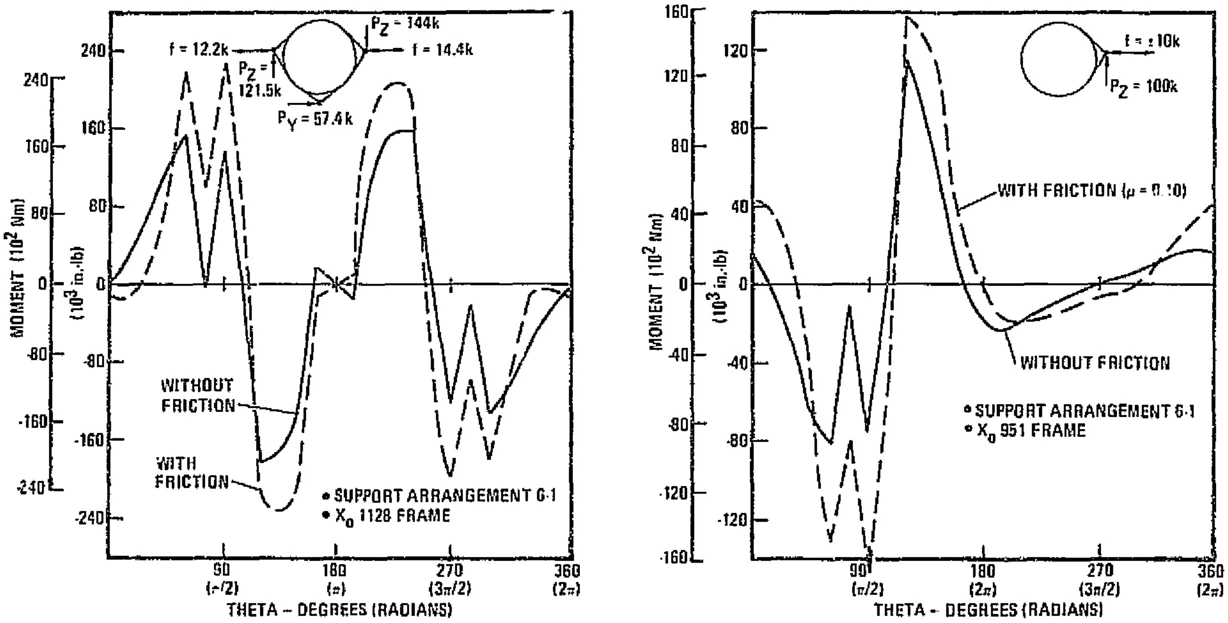


Figure 4.2-37. Effect of Friction on Frame Bending Moments

Table 4.2-18. Friction Effect on Frame Weights

Frame Station	Support Config.	Weights			
		With Friction	Without Friction	Difference	
				lb	kg
951	6-1	38.70	33.45	5.25	2.38
	1-1	40.79	34.00	6.79	3.08
	1-2	38.70	33.44	5.26	2.39
	2-1	32.31	27.70	4.61	2.09
	2-2	30.92	26.40	4.52	2.05
1128	6-1	72.10	55.65	16.45	7.47
1187	1-2	71.35	42.65	28.70	13.03
	2-2	70.10	40.70	29.40	13.35

Table 4.2-19. Performance Impact Due to Friction

Config.	ΔW lb	ΔW (kg)	ΔPL Dep. lb	ΔPL Dep. (kg)	ΔPL Ret. lb	ΔPL Ret. (kg)
1-1	6.8	(3.1)	-17.8	(8.1)	- 9.4	(- 4.3)
1-2	34.0	(15.4)	-89.1	(-40.4)	-46.9	(-21.3)
2-1	4.6	(2.9)	-12.1	(- 5.5)	- 6.3	(- 2.9)
2-2	33.9	(15.4)	-88.8	(-40.3)	-46.8	(-21.2)
6-1	21.7	(9.8)	-56.9	(-25.8)	-29.9	(-13.6)

Further comparison of the ±Y friction moment data with that shown in Figure 4.2-37 indicates a considerably lesser friction Δ moment with the later data. Consequently the frame Δ weight and Tug Δ performance impacts were assumed to be reduced from the already low values shown in Tables 4.2-18 and 4.2-19, and no further weight/ performance computations were conducted.

The lower half of Figure 4.2-39 illustrates the cause and effect of friction forces directed normal to the support frame planes. In both cases the effect is to produce an overturning moment on the Tug fittings, which neither the basic sidewall nor the support frames are designed to withstand. Consequently a new lightweight stabilizing brace is required to distribute the friction force, as shown, as a pair of low-magnitude in-plane "kick" loads, K, at the support frame and an existing adjacent ring.

The summary conclusion of the friction evaluation is, therefore, that although friction forces are real and their effects must be included in Tug design, their overall impact is small and they do not act as significant discriminators between candidate support systems.

4.2.3.3 Support Fitting Designs. Design of the Tug/Orbiter support fittings was conducted in two steps. The initial designs were based on loads using NASA baseline Tug accelerations and on Orbiter trunnion and keel receptacle details (and the corresponding implied Tug fitting details) from existing RI layouts. At that time there were no handling concept constraints nor friction load considerations. The updated designs were based on new loads using the accelerations in MSFC PF02-75-31, on compatibility with the latest KSC handling concept, on assumed Orbiter keel fitting revision to accommodate rotational deployment, and on reduced shaft and bearing diameters for the Z and X/Z fittings. In addition, the updated designs incorporated the friction stabilization brackets identified in Section 4.2.3.2. Both the initial and

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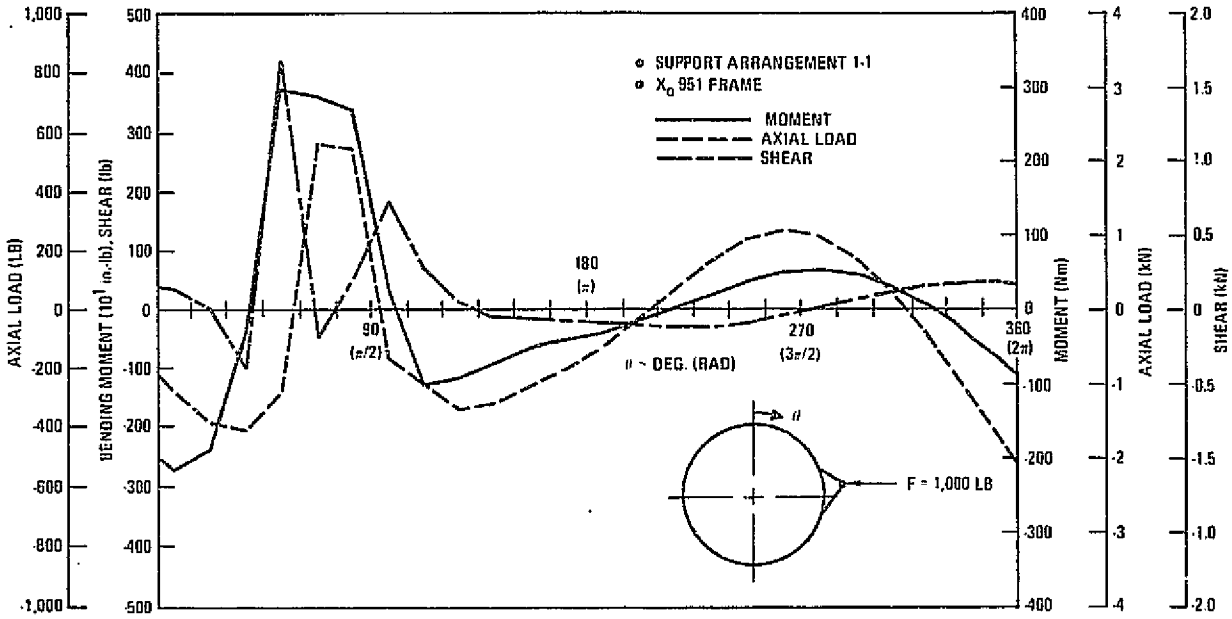


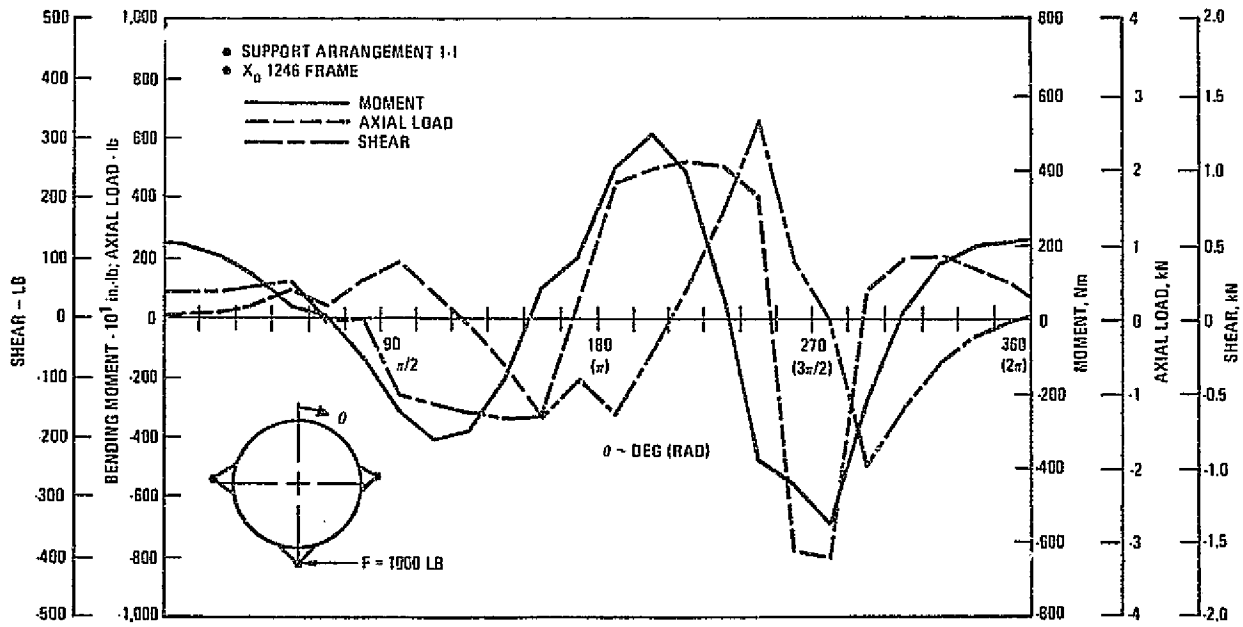


Figure 4.2-38. Frame Loads Due to Unit Friction Forces

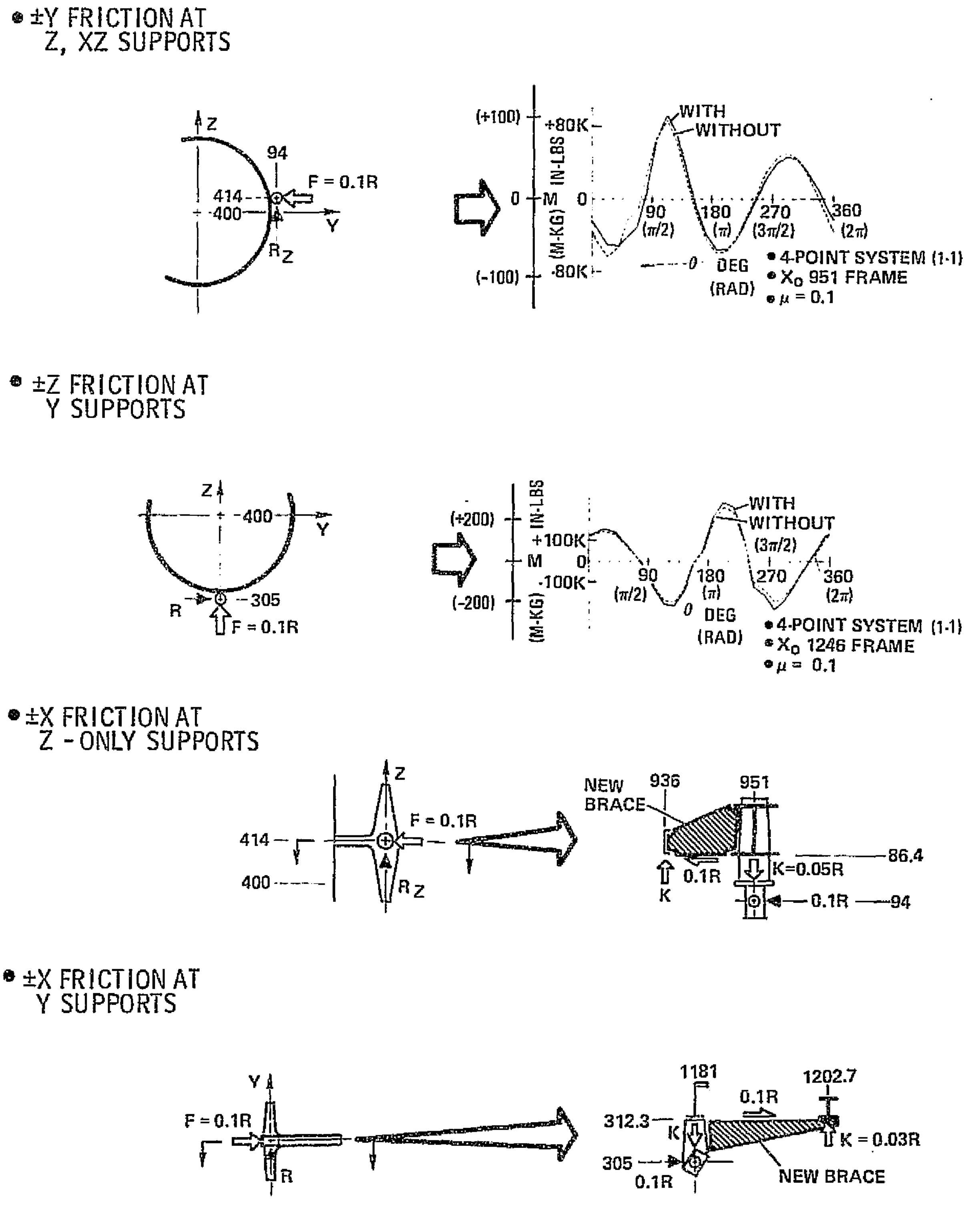


Figure 4. 2-39. Impacts of Friction at Supports

updated fitting designs included allowance for appropriate safety factors and margin of safety. Table 4.2-20 compares the criteria, ground rules, and assumptions used in the two cycles of support fitting design.

The initial and updated configurations of a typical Z fitting and X longeron are shown in Figures 4.2-40 and 4.2-41 respectively. In the initial concept, all primary (X/Z) and stabilizing (Z-only) supports incorporated the same concept of load introduction and each support installation consisted of three subassemblies: bearing, shaft, and fitting.

Table 4.2-20. Support Fitting Design Criteria

Item	Initial	Update	Basis
Shaft Dia. in. (cm)	3.75 (9.52)	3.25 (8.75)	RI L/O: VL 70-544105 JSC Chart: NASA-5-75-10004 MSFC Dwg.: 30A90707 KSC Dwg: PRC-0538-6
Bearing Width Dia. in. (cm)	2.00 (5.08) 4.70 (11.93)	2.00 (5.08) 4.00 (10.16)	RI L/O: (same) JSC chart: (same)
Y-Motion Outbd Inbd in. (cm)	2.00 (5.08) 2.00 (5.08)	2.00 (5.08) 1.50 (3.81)	RI L/O: (same) + 0.50 Tug motion JSC chart: (same)
Loads Accelerations	MSFC B. L.	New MSFC	MSFC 68M00039-1 MSFC PF 02-75-31
Safety Factors	1.4/1.1	1.4/1.1	MSFC-HDBK-505
Margin	+0.25	+0.25	MSFC 68M00039-1
Friction ±Y	Yes (μ = 0.1)	Yes (μ = 0.1)	NASA request
±X, ±Z	No (μ = 0.1)	Yes (μ = 0.1)	Section 4.2.3.2
AGE Config.	Unspecified	New KSC	KSC dwg: (same)

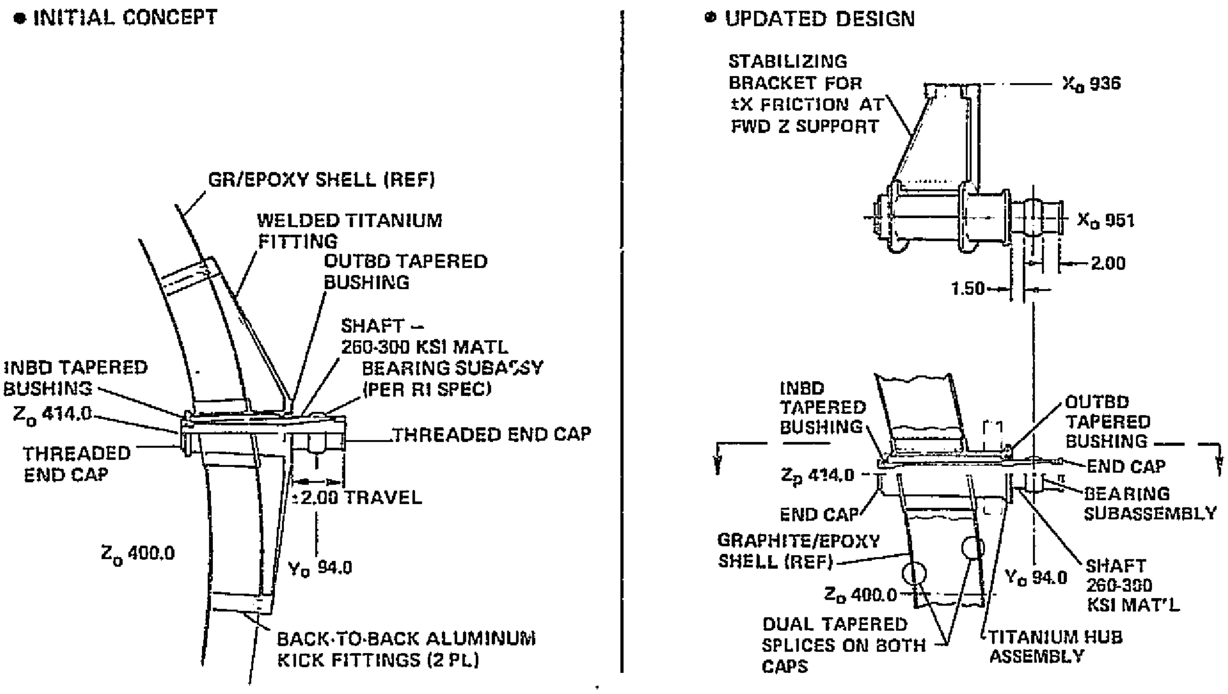


Figure 4.2-40. Typical Z Support Fitting

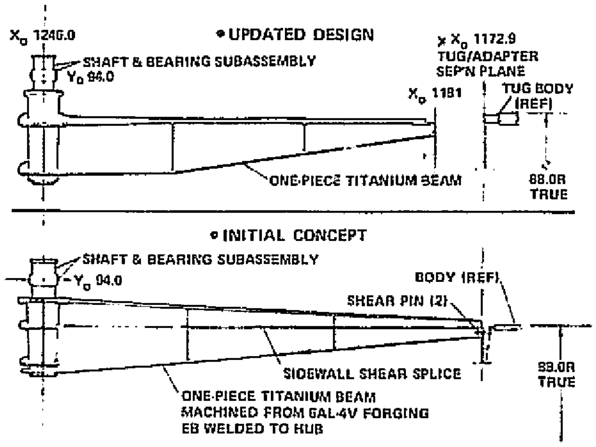


Figure 4.2-41. Typical X Support Longeron

The bearing subassembly, comprised of spherical segment, outer race, and inner liner, was assumed to be covered by Rockwell specification to assure compatibility with the Orbiter cargo retention system.

The shaft subassembly consisted of a turned shaft plus threaded caps at each end. The shaft required steel or other alloy of 260-300 ksi (1790-2070 MPa) tensile strength to provide the required +25 percent margin of safety under maximum loads. Load transfer from shaft to fitting was accomplished entirely in bearing to eliminate a shaft/fitting binding radius and thereby both minimize the effective overhang of the applied load and maximize fatigue life. Incorporation of matching shallow tapers on the shaft and its support bushings also permitted ease of installation and removal and provided a reaction for any inboard thrust due to Y-direction friction between the bearing subassembly and the shaft. Any outboard friction was resisted by the inner cap.

The fitting subassembly was comprised of a titanium weldment and the two shaft support bushings. The weldment consisted of two Z beams machined in detail then electron-beam welded to a central hub. After heat treatment and aging, surfaces interfacing with the shell structure were finish-machined to contour. Loads were sheared from the fitting beams into the outer surface of the composite shell structure through fully bonded plus mechanically fastened joints. Tangs welded to the fitting hub provided similar introduction of Z loads into the shell frame inner cap. Residual kick loads at the ends of the Z-load beams were introduced to the shell frame web by back-to-back aluminum tees, which also provided web stiffening and shear redistribution. The beam/tee tension bolts were installed through oversize holes to avoid high localized bearing stresses in the composite frame cap.

As a result of the update, the Z-only and X/Z fittings were resized to reflect the support reactions resulting from the latest MSFC accelerations and to provide compatibility with the latest NASA-KSC ground handling concept and shaft/bearing diameter reductions. The initial concept transferred reactions into the Tug through a high-strength shaft supported by discrete bushings in a titanium fitting. This approach was retained but the titanium fitting was reconfigured to eliminate the gussets outside the body skin line and to provide a flanged cylindrical hub instead. The hub O.D. provides a grip surface for the KSC AGE system yet minimizes total fitting weight by providing a support at the farthest permissible outboard location on the smaller diameter shaft, thereby minimizing shaft bending moment. The technique for introducing loads into the outboard frame cap was revised by substituting a pair of tapered tangs (similar to the previous inboard splice technique) for the Z beams. The forward Z fitting was further revised to incorporate a stabilizing bracket to react the overturning moment caused by ±X-direction friction.

In addition to the longitudinal load it must carry, major kick loads also occur at both ends of the X longeron. In the initial concept the aft kick load was sheared into the shell frame web from splice blades welded to the fitting hub and the forward kick load was transferred by shear pins across the adapter/Tug separation plane to a radial fitting in the oxidizer tank support frame at X_O 1172.9. The longitudinal load was transmitted into the graphite/epoxy sidewall through a shear splice lying between the primary bending caps and extending the full length of the longeron. The entire longeron was machined in one piece from a 6Al-4V Titanium forging and was electron beam welded to the hub portion of the Z fitting. In the updated configuration, the longeron was revised to delete the external ramp to expose the full hub cylinder for AGE attachment. In addition, the forward kick load reaction was relocated to station X_O 1181 on the aft Y support frame. This eliminated the former shear pin load transfer across the Tug/adapter separation plane, thereby reducing the Tug/adapter interface complexity somewhat by eliminating the precision alignment required for the radially loaded pins.

The material and method of longeron manufacture were unchanged, but the depth decreased due to elimination of the external ramp, which resulted in increased cap thicknesses, although the penalty was largely offset by elimination of a separate sidewall shear splice.

The initial and updated Y fitting configurations for the X_O 1181 location are shown in Figure 4.2-42. The Y-load fitting installations at other locations were similar in concept but differed in detail as a function of support station. Each installation consisted of a steel cap mounted on a machined titanium beam, in turn supported by the composite shell and, where necessary due to offset from a major frame, by longitudinal machined aluminum beams.

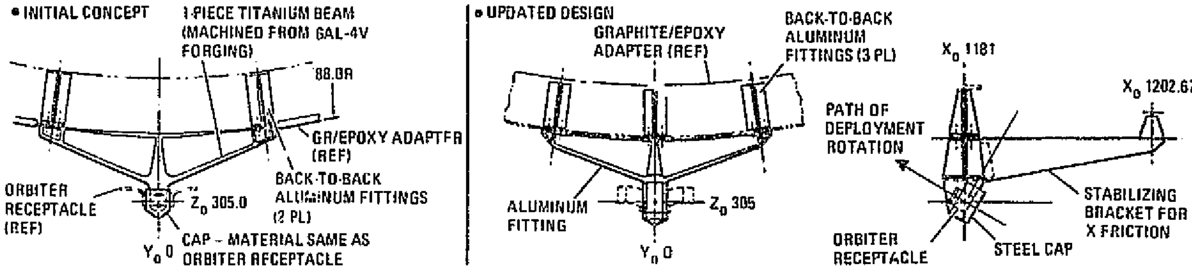


Figure 4.2-42. Typical Y Support Fitting

The steel cap provided surfaces that contacted the Orbiter bridge beams during installation, removal and load transfer, and was attached to the beam by mechanical fasteners to accommodate replacement. The beam was machined in one piece from a titanium forging. At Station 1181, sufficient depth was available to permit the beam to mount on the shell outer surface. In the Z- support arrangements, in-plane kick loads at each end of the beam were reacted by a pair of identical machined aluminum beams spanning longitudinally between the major shell frames at X_O 1172.9 and 1187. Insufficient depth was available at X_O 1249 for outer surface mounting, but proximity of the aft-most adapter frame (X_O 1246) permitted the beam to scab onto the frame web for the full frame depth. In-plane loads were applied directly to the frame web. Yaw-bending kick loads resulting from the 3-inch (7.62 cm) eccentricity were reacted at the ends of the beam by machined aluminum longerons, which extended forward approximately 24 inches (61 cm) to the first adapter stabilizing frame.

In each location, the corresponding Orbiter bridge beam, as then configured, precluded rotational deployment. Modifying the bridge beam concepts at X_O 1181 and 1249 was necessary to permit rotational deployment. For example, this was accomplished at X_O 1181 by lowering the central portion of the basic beam and reinforcing the sides to carry local twisting as shown in Figure 4.2-43. The frame interface provisions in the Orbiter were unaffected. The steel interface plate retained the same cross-section, but an entrance guide was required at the forward end to correct misalignment during rotation into the support.

In the update task, the Y-fitting designs were revised to align the interface cap with the path of motion defined by rotation about the deployment pivot axis (X_O 1246, Z_O 414)

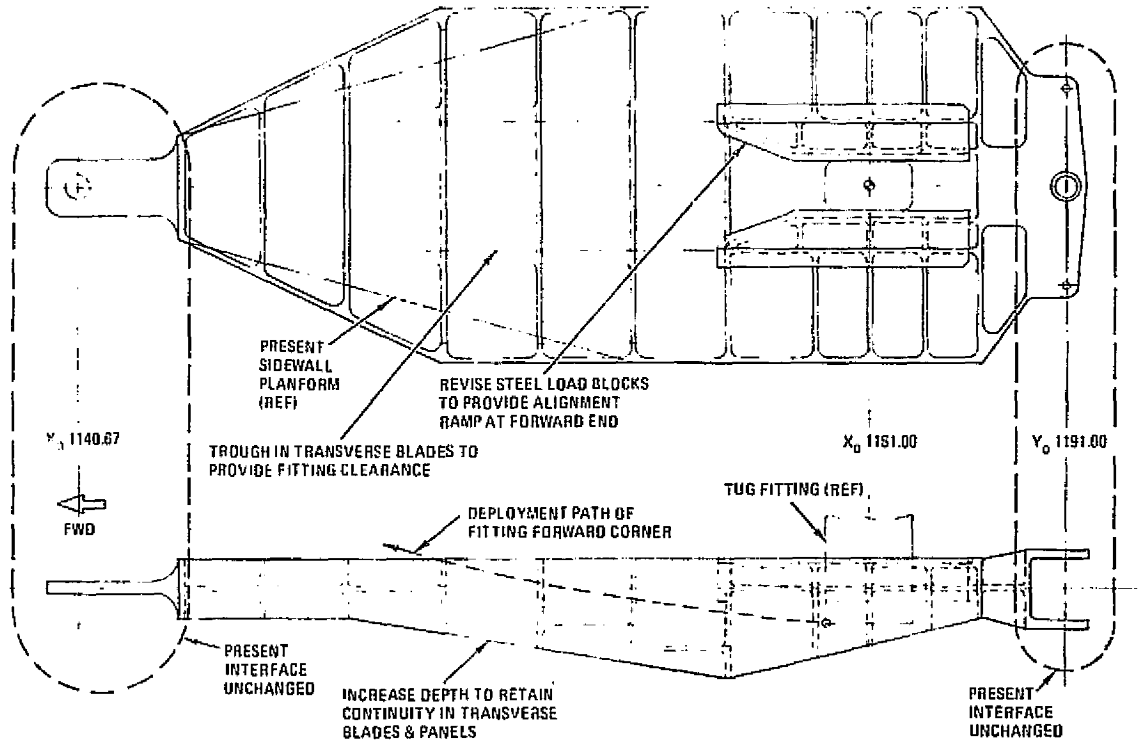


Figure 4.2-43. Modified Orbiter Keel Fitting Concept to Accommodate Rotational Deployment

and to revise the choice of material from titanium to aluminum. The X_0 1181 Y-fitting design is shown illustrating both the reoriented cap and an added stabilizing bracket, which reacts overturning due to ±X friction. A third pair of back-to-back fittings was required on the X_0 1181 frame web to react the stabilizing bracket kick load, and a similar pair was required to introduce the opposite kick into the X_0 1202.67 frame.

Support fitting weights were developed parametrically as a function of applied reaction at each support location to assist the weight/performance evaluation of candidate support systems. Figure 4.2-44 provides the parametric curves and Table 4.2-21 summarizes the fitting weights for the candidate support arrangements under consideration before final selection.

4.2.3.4 <u>Handling Provisions</u>. The initial handling investigation was performed to determine a suitable technique for both horizontal and vertical installation and removal of Tug plus spacecraft from the Orbiter cargo bay.

Handling loads could be minimized for vertical installation by using attachment points close to the Tug longitudinal axis. However, handling equipment clearances, nominally 3.0 in. (7.6 cm) (per JSC 07700), had to be maintained between both the Orbiter (fitting guides and sill longeron) and Tug body structure, and the AGE handling frame. Fittings

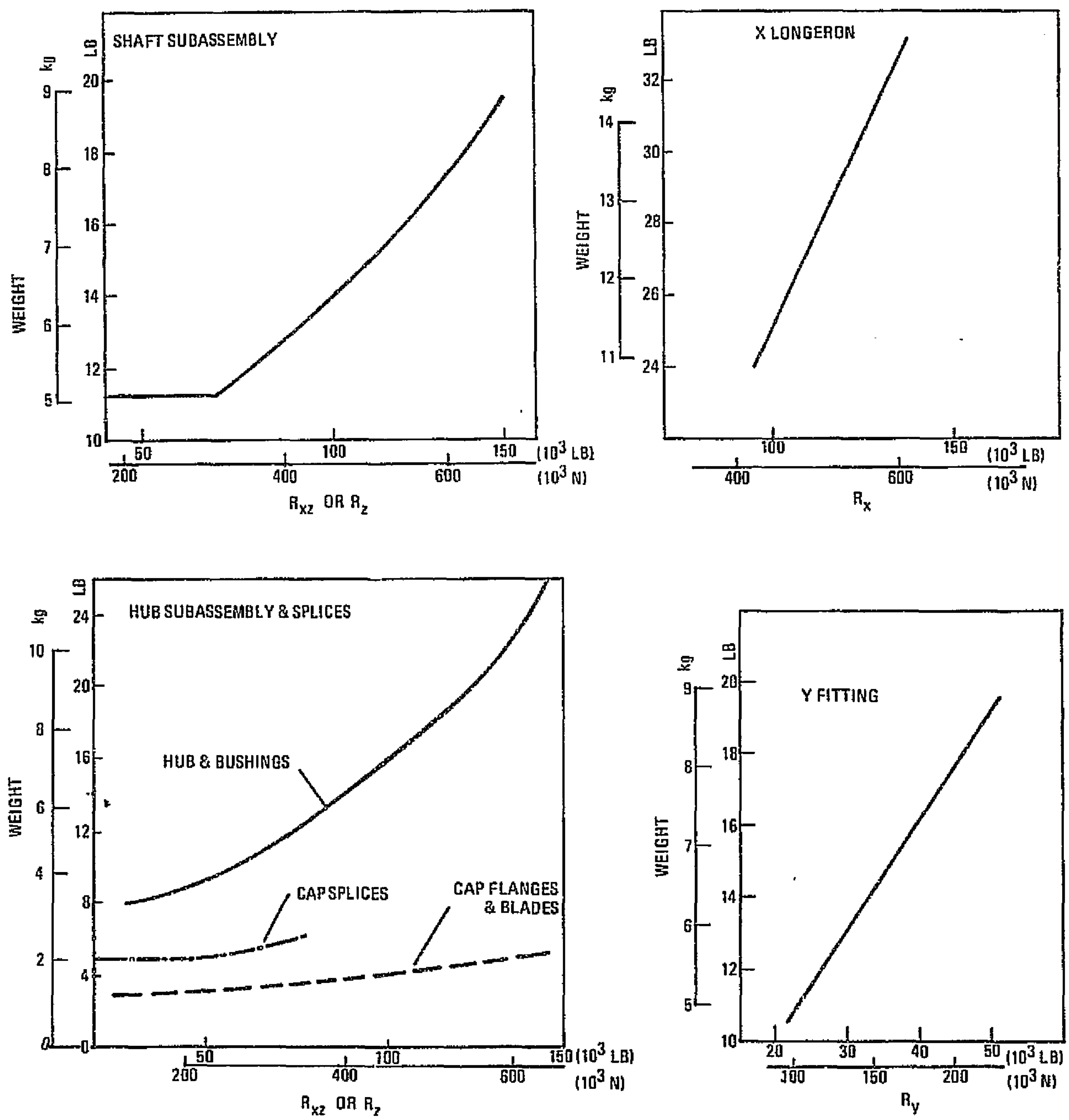
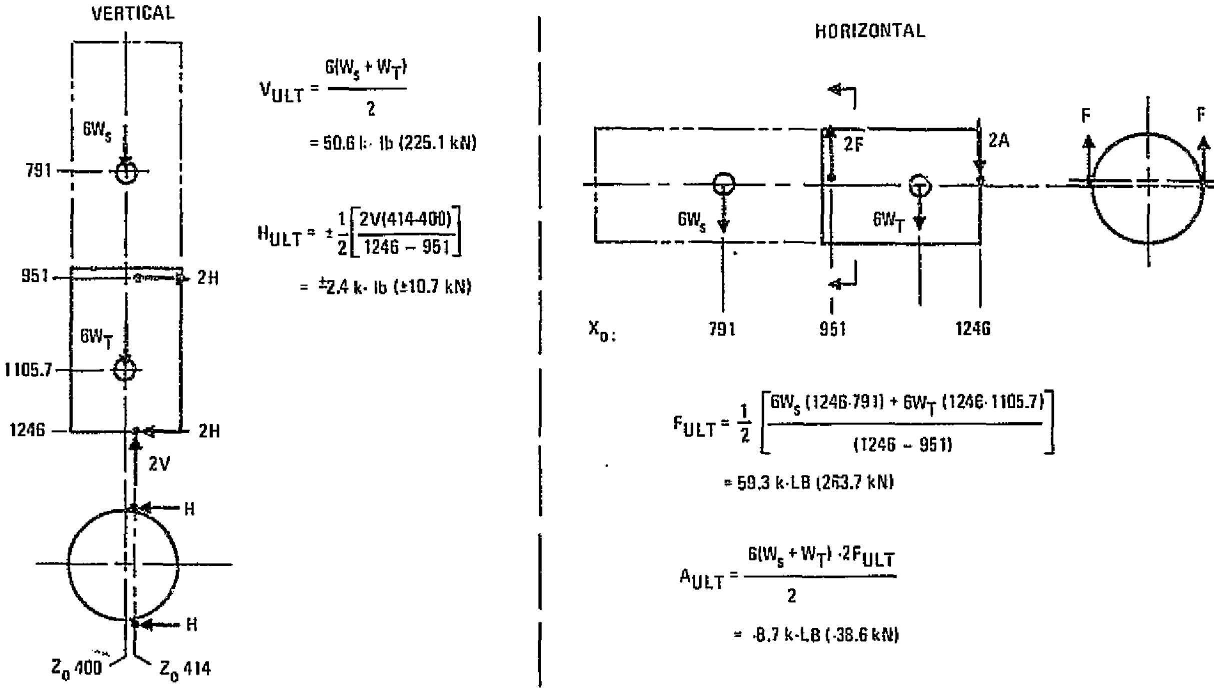


Figure 4.2-44. Parametric Support Fitting Weight Curves

Table 4.2-21. Support Fitting Weights for Final Candidate Support Arrangements

Support Arrangement	Fitting Locations and Weights										
	Tug						Non-Tug				
	Y_1	Y_2	Z_3	Z_4	$\Sigma(10^3$ lb)	$\Sigma(10^3$ kg)	X_1Z_1	X_2Z_2	Y_1	$\Sigma(10^3$ lb)	$\Sigma(10^3$ kg)
4 Pt, 1249Y (1-1)			32.8		32.8	14.9	85.9	85.9	17.7	189.5	86.0
4 Pt, 1128Y (1-1A)	17.7		32.8		50.5	22.9	69.6	69.6		139.2	63.2
5 Pt, Balanced (2-1)			28.3	28.3	56.6	25.7	82.9	82.9	17.7	183.5	83.3
5 Pt, Redundant (2-1R)			28.5	28.5	57.0	25.9	83.1	83.1	17.7	183.9	83.5
6 Pt, Balanced (4-1)		17.5	28.3	28.3	74.1	33.6	64.4	64.4	12.1	140.9	64.0
6 Pt, Redundant (4-1R)		16.9	28.9	28.9	74.7	33.9	64.9	64.9	13.1	142.9	64.9

placed below the Tug/Orbiter attachment plane (Z_O 414) violated clearance restrictions. The most obvious choice from a standpoint of reduced loads and Tug weight penalty was to use the primary Tug support fittings as handling attachment points. Figure 4.2-45 shows the resulting handling loads, and Figure 4.2-46 illustrates the provisions incorporated in the initial support fitting designs (reference Section 4.2.3.3) to accommodate handling. Installation of a V-block fitting on the Tug deployment



NOTES:

(1) W_s = 11.0 k-LB (4,994 kg); W_T = 5.9 k-LB (2,660 kg)

(2) ALL HANDLING INTERFACES ON TUG/ADAPTER AT Z, X/Z SUPPORTS

(3) INCLUDES JSC SAFETY FACTORS (LIMIT = 2 x STATIC; ULT = 3 x LIMIT)

Figure 4.2-45. Handling Loads

adapter X/Z fittings allowed the AGE handling frame to be used like a fork lift. Tug clearance was acceptable since the 'fork' contacted the fitting aft of the deployment adapter shell, and the fitting interface shown provided suitable shaft clearance for Orbiter latching and unlatching. A similar forward drag fitting was attached through a V-block to the Tug station 951 Z-only fitting(s). The Tug clearance was tighter at this location (since the Tug structural shell extends both forward and aft from the fitting) but was still acceptable. Induced handling loads, including the large safety factors required, fall within Tug support fitting flight loads design capability (Figure 4.2-45), thereby imposing a negligible weight penalty due only to the addition of bearing surface material.

Horizontal handling was also accommodated by using Tug plus deployment adapter primary support fittings. The plus-or-minus 2-inch (5 cm) bearing travel provided on

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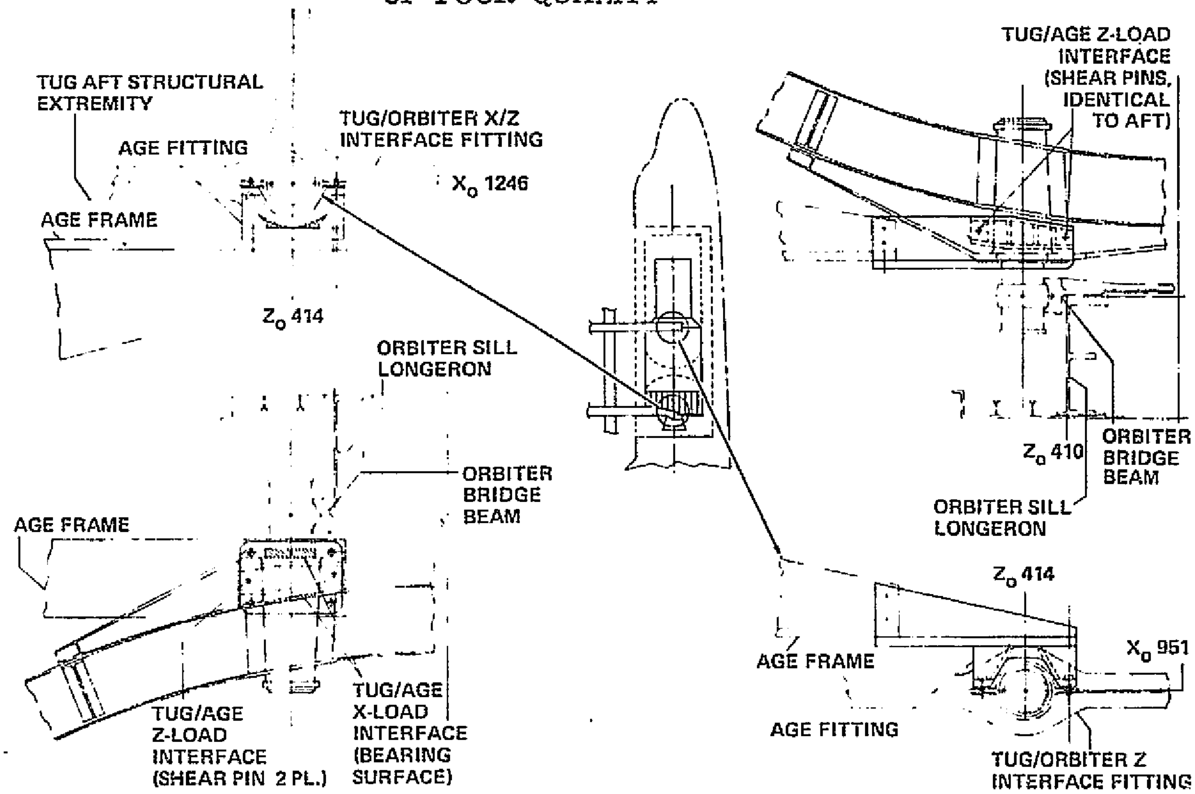

Figure 4.2-46. Handling Provisions for Tug/Spacecraft Changeout Using Initial Support Fitting Concept

the fitting shaft left sufficient space for split ring attachment inboard of the slide bearing. Spreader bar/sling connection to the 3 (or 4) latched split rings provided horizontal handling capability.

As mentioned in Section 4.2.3.3, one of the considerations driving the update of the Tug/Orbiter interface fittings was the KSC handling concept data received during the study. This resulted in a review of the initial handling provisions plus those presented in various NASA concepts. Two conflicting design goals existed, which made rapid solution of this interface difficult: 1) the Tug (and other Orbiter payloads) require their half of the fitting to impose a minimum vehicle weight penalty. As in the initial concept, it was therefore very desirable to use the Tug to Orbiter attachment fittings as pickup points for ground handling since this precluded the need for Tug special-purpose attachment provisions and thereby avoided any associated weight penalties, and 2) NASA Kennedy Space Center desired a standard interface on all Orbiter payloads for ground handling purposes. The Tug, since it is the largest diameter Shuttle payload currently identified, was considered to be a design driver for configuring this standard attachment.

The key issues in the update task then were:

a. Can the primary support fittings still be adapted for ground handling of the Tug (with and without a spacecraft attached) in both the vertical and horizontal modes?

b. If so, to what extent is the Tug either penalized or constrainted?

The various concepts investigated are compared and the preferred concept selected is shown in Figure 4.2-47.

The initial Convair concept, using the fitting bracket as a "fork lift" attachment, was unacceptable since it was not compatible with the KSC stanardized handling concept. Three NASA proposed configurations provided this desired standard AGE interface through a fitting shaft extension. In each case, however, the Tug was penalized due to the shaft weight increase needed to carry the higher bending moments at the root of the shaft, which resulted from incorporating integral handling surfaces on the shaft itself. A slightly different approach was selected to permit both standard handling and optimized Tug (and other payload) fitting design. In this concept, the shaft is similar to the initial Convair concept but an ungusseted larger diameter hub is provided to more efficiently carry fitting loads and to provide a location for AGE attachment. Orbiter payloads which are lighter than the Tug would retain a specified hub outer diameter but could adjust the hub cylinder material thickness and properties as required for their specific loading conditions.

Specific detail dimensions D_O, Y_O, and Y_i in the selected configuration were based on a consensus of the values shown in the three NASA concepts. The shaft moment values shown were based on an assumed bearing reaction load of 103.7 k lb (461.5 kN) applied at Y_o 94 (representing the maximum X/Z resultant in support arrangement 4-1 using accelerations in MSFC PF02-75-31). The qualitative shaft weight assessment was based on a comparison of the parameter M/D_i^2 for each configuration since shaft line load, and therefore shaft wall thickness, are roughly proportional to it.

4.2.3.5 Deployment Adapter Structure. The replacement, in the reference vehicle configuration, of the NASA bifurcated adapter with a cylindrical concept, similar to the Convair STSS configuration, was discussed in Section 4.2.1.1. To expedite support reaction and body loads computation in Sections 4.2.2.2 and 4.2.2.3, the NASA baseline Tug mass properties in MSFC 68M00039-2 were initially assumed to apply to the cylindrical adapter (Section 4.2.1.5). Described in the following text are the baseline structural characteristics and development of the updated weights for the reference cylindrical adapter.

The following ground rules were used in the initial adapter design and analysis:

a. Used the same basic sandwich sidewall as the reference Tug (as in Figure 4.2-5).

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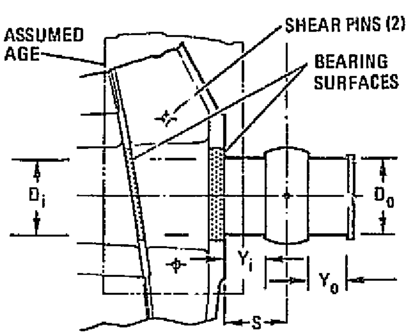
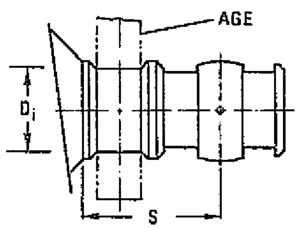
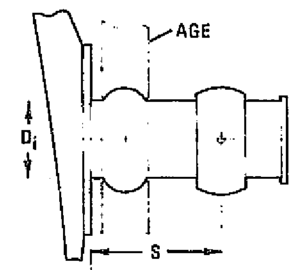
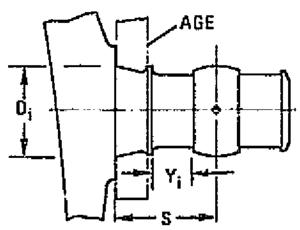
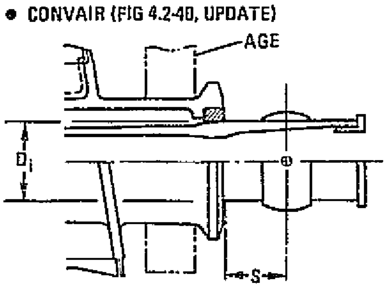
CONCEPT	DIMENSIONS, IN., (CM) D_o	D_i	Y_o	Y_i	S	SHAFT MOMENT	SHAFT WEIGHT	COMPAT W/AGE?	SELECTED
• CONVAIR (FIG 4.2-40, INITIAL) 	3.75 (9.53)	3.75 (9.53)	2.00 (5.08)	2.00 (5.08)	3.00 (7.62)	10^3 IN.-LB (10^3Nm) 311.1 (35.2)	LOW	NO	
• KSC (DWG NO. PRG0538-6) 	3.25 (8.26)	3.75 (9.53)	1.50 (3.81)	1.50 (3.81)	5.50 (13.97)	570.4 (64.5)	HIGH	YES	
• MSFC (DWG NO. 30A90707) 	3.25 (8.26)	3.25 (8.26)	2.00 (5.08)	1.50 3.81)	5.50 (13.97)	570.4 (64.5)	HIGHEST	YES	
• JSC (CHART NO. NASA-S-75-10004) 	3.25 (8.26)	4.00 (10.16)	2.00 (5.08)	1.50 (3.81)	4.50 (11.43)	466.7 (52.7)	MEDIUM	YES	
• CONVAIR (FIG 4.2-40, UPDATE) 	3.25 (8.26)	3.25 (8.26)	2.00 (5.08)	1.50 (3.81)	2.50 (6.35)	259.3 (29.3)	LOW	YES	✓

Figure 4.2-47. Handling Concept Comparison and Selection

b. Provided sidewall reinforcement adjacent to the X-longerons based on peaking factors developed from the Convair STSS.

c. Provided a forward kick frame for X-longeron support at the same station as the STSS configuration (X_O 1197.3).

d. Used 16 Tug/adapter latches and used STSS finite element data to govern latch longeron sizing.

e. Used NASA baseline Tug latch concept and weight.

f. Sized X-longeron kick frames using coefficients developed from STSS data.

g. Used STSS percentages for potting and facing tolerance allowances.

h. Included subsystems support provisions weight allowance based on STSS data.

i. Used the same support fitting weights as in Section 4.2.2.3.

j. Used the reference frame concept of Figure 4.2-7 at major frame locations.

Sidewall. The sidewall cross section is shown schematically in Figure 4.2-48; details of the frame/shell joints are shown in Figure 4.2-49. The solid laminate pans shown at X_O 1172.9, 1197.3, and 1246 were based on the concept shown in Figure 4.2-6. The primary advantages of the pan concept are: 1) elimination of a majority of the potting and inserts otherwise required to introduce frame loads to the ultra-thin sandwich facings, and 2) the solid laminate blade and heavier core permit transfer of loads into the facings in shear, thereby precluding tension failure of the facing/core bond in the ramp areas.

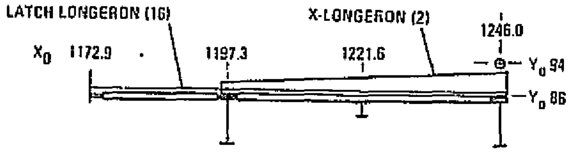


Figure 4.2-48. Adapter Sidewall Cross Section Schematic

Reinforcement to accommodate axial load peaking adjacent to the X longerons was based on the same approach as used in Section 4.2.3.3. Facing thickness were increased further still due to the increased X reactions at the X_O 1246 support. The resulting characteristics of the adapter sidewall are shown in the flat pattern of Figure 4.2-50. Unit weights were computed for each of the five pan configurations and summed as shown in Table 4.2-22. Basic (unreinforced) panel weights were based on the unit weight specified in Figure 4.2-5 and the net span dimensions remaining after deducting the pan widths. The resulting weights are given in Table 4.2-23. The

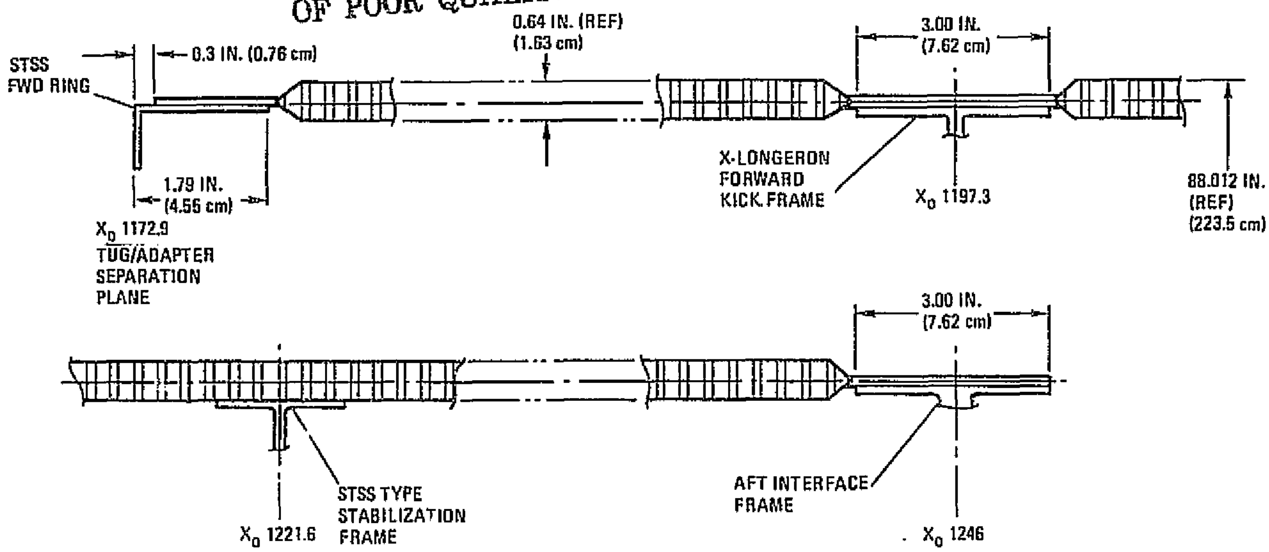


Figure 4.2-49. Adapter Frame/Shell Joints

facing reinforcement weight was based on the Δ thicknesses shown (per facing) summed over the appropriate panel surface areas, as shown in Table 4.2-24.

Latch Longerons. Latch loads were developed by using the peaking factors shown in Figure 4.2-51 to modify conventional theory body loads at the Tug/adapter separation plane (X_0 1172.9). The peaking factors were developed from Convair STSS finite element data, and the body load envelopes were plotted using the computer program discussed in Section 4.2.2.3. Figure 4.2-52 compares the conventional theory and modified loads, and illustrates the average load intensity tributary to each latch.

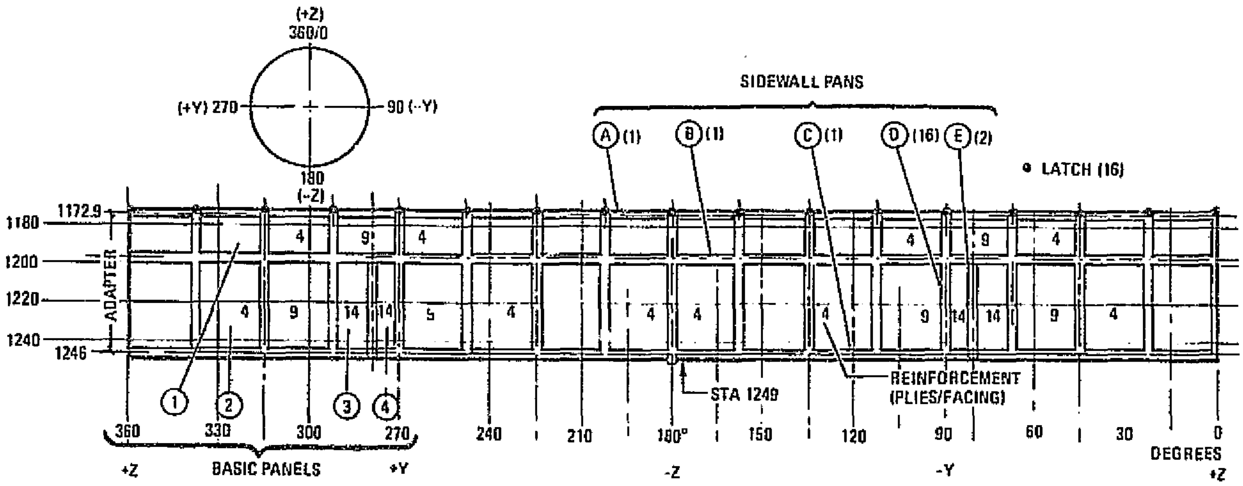


Figure 4.2-50. Deploy Adapter Flat Pattern

Table 4.2-22. Pan Weights

Type	b		w		L		Qty	W	
	in.	cm	lb/in.	g/cm	in.	cm		lb	kg
A	1.60	4.06	0.0210	3.75	550.97	1399.5	1	11.57	5.25
B	1.60	4.06	0.0210	3.75	550.97	1399.5	2	23.14	10.51
C	3.10	7.87	0.0291	5.20	550.97	1399.5	1	16.03	7.28
D	0.90	2.29	0.0172	3.07	66.7	169.4	32	36.71	16.67
E	1.30	3.30	0.0193	3.45	45.5	115.6	4	3.51	1.59
TOTAL								90.96	41.30

Table 4.2-23. Panel Weights

Type	ΔX		ΔC		A		Qty	W	
	in.	cm	in.	cm	in.^{2}	cm^2		lb	kg
1	18.4	46.7	30.14	76.6	554.58	3577.9	16	27.95	12.69
2	43.0	109.2	30.14	76.6	1296.02	8361.4	14	57.15	25.95
3	43.0	109.2	25.04	63.6	1076.02	6942.1	2	6.78	3.08
4	43.0	109.2							
TOTAL								91.88	41.71

Computation of the modified loads at the latch locations is summarized in Table 4.2-25. Note from the table that the maximum latch tension at four of the nine points investigated resulted from the product of a negative peaking factor and a compressive axial load. It is clear from Figure 4.2-52 that the latch design loads fall into two rather distinct sets: 1) a design load of 850 lb/in. (1988 N/cm) is suitable for the latches located on either side of the X longerons plus the latch on the vehicle top (+Z) centerline, and 2) all others are enveloped by a 450 lb/in. (788 N/cm) design load. Consequently, although all 16 latches would no doubt be identical, two distinct longeron designs were permissible and they were sized accordingly. All longerons were assumed to extend the full length of the adapter and to be machined from aluminum alloy of F_{TU} = 70 ksi (482 MPa). Allowing for an ultimate factor of safety of 1.4, and

Table 4.2-24. Facing Reinforcement

Panel Type	Area		Reinf. Plies(1)	t(2)		Panel Qty	W(3)	
	in.^{2}	cm^2		in.	cm		lb	kg
1	554.58	3577.9	8	0.0180	0.0457	4	2.32	1.05
1	554.58	3577.9	18	0.0405	0.1029	2	2.61	1.18
2	1296.02	8361.4	8	0.0180	0.0457	6	8.12	3.69
2	1296.02	8361.4	18	0.0405	0.1029	4	12.18	5.53
3, 4	1076.02	6942.1	28	0.0630	0.1600	2	7.86	3.57
TOTAL							33.08	15.02

Notes: (1) Total of two facings.
(2) 0.00225 in. (0.00572 cm) per ply.
(3) 0.058 lb/in.^{3} (1.605 g/cm^3).

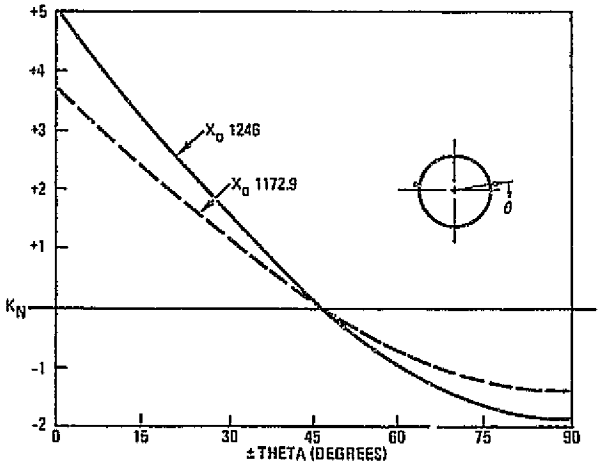


Figure 4.2-51. Axial Load Peaking Factors

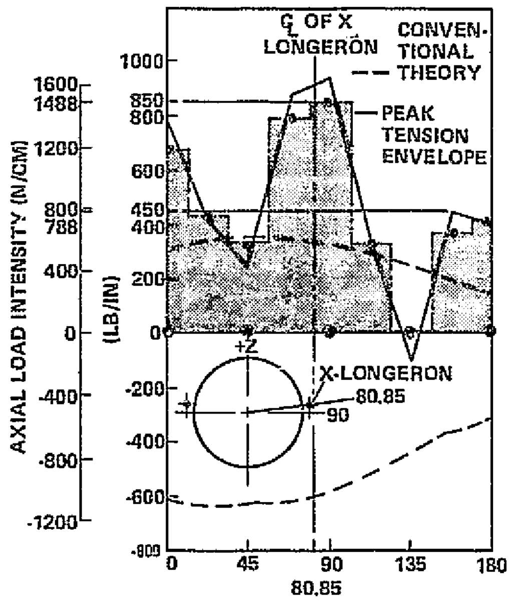


Figure 4.2-52. Determination of Separation Latch Load Distribution

a margin of safety of +0.25 plus providing a latch attach pad at the loaded end, tapering the area uniformly to a minimum area at the opposite end and allowing a 10 percent penalty for fillets and tolerances resulted in the weights shown in Table 4.2-26.

Frames. Two load configurations were applied to the adapter frames as shown in Figure 4.2-53. The type A loading occurred on the kick frame at X_0 1197.3 and also on the aft frame at X_0 1246 in those support arrangements with only X supports on the

Table 4.2-25. Computation of Modified Loads at Latch Locations

Latch Angle From		n_{XT} (1) (Theory)			n_X (1) (Modified)		n_{XC} (1) (Theory)			n_X (1) (Modified)	
Top	X	lb/in.	N/cm	K_n	lb/in.	N/cm	lb/in.	N/cm	K_n	lb/in.	N/cm
90	+ 9.15	320	560	2.90	928	1624	-580	-1015	2.90	-1682	-2944
112.5	+31.65	280	490	1.02	286	501	-510	- 893	1.02	- 520	- 910
135	+54.15	240	420	-0.43	-103	-180	-430	- 753	0.43	- 186	- 324
157.5	+76.65	200	350	-1.25	-248	-434	-360	- 630	-1.24	+ 446	781
180	+99.15	160	280	-1.31	-210	-368	-310	- 543	-1.31	+ 406	711
67.5	-13.35	340	595	2.53	860	1505	-610	-1068	2.53	-1543	-2700
45	-35.85	350	613	0.71	249	436	-620	-1085	0.71	- 440	- 770
22.5	-58.35	330	578	-0.63	-208	-364	-630	-1103	-0.63	+ 397	695
0	-80.85	300	525	-1.31	-393	-688	-600	-1050	-1.31	+ 786	1376

Notes: ⬭ = Maximum tension at each latch location.

(1) Tension = +; compression = -.

Table 4.2-26. Latch Longeron Weights

Type	Design n_T		Unit Wt		Qty	Total Wt	
	lb/in.	N/cm	lb	kg		lb	kg
A	850	1488	3.57	1.62	5	17.83	8.09
B	450	788	2.11	0.96	11	23.21	10.54
						41.04	18.63

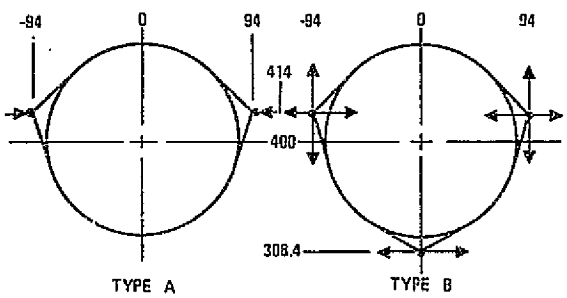


Figure 4.2-53. Adapter Frame Loading Configurations

adapter (Family 6 and all -3 options). Bending moments for the Type A loading were determined using the appropriate kick load and the Moment Coefficient curve of Figure 4.2-36 (Section 4.2.3.2). Frame weights were computed from the parametric data in Section 4.2.2.3.

Except in those support arrangements noted above, the Type B loading occurred at the X_0 1246 frame. Total bending moments for this load case were conservatively assumed to consist of the linear sum of the moment distributions due to the X and Z reactions applied separately. The X moment distribution was determined as above and the Z moments were computed using the appropriate coefficient distribution in Figure 4.2-36 (Section 4.2.2.3). It was assumed that the linear sum of the X+Z moments would envelop the effects of moments due to the Y reaction, if present. Frame weights were again computed using the Section 4.2.2.3 parametric data. The resulting weights were: Type A frame, 42.9 lb (19.5 kg); Type B frame: 58.9 lb (26.7 kg).

Weight Summary. Table 4.2-27 presents the initial weight summary for the two basic options of the reference configuration adapter (X-only supports and X/Y/Z supports). A third adapter configuration was required in support arrangement 7-1 only, since only one Z support was required at X_0 1246. Substitution of an X-only fitting for an X/Z fitting in the X/Y/Z configuration resulted in a weight of 862.8 lb (391.7 kg) for that adapter. The final adapter weight summary, which incorporates any configuration revisions since the initial design, is presented in Volume III, Section 4.5.

Table 4.2-27. Adapter Weight Summary

Item	Weight			
	X Only		X/Y/Z	
	lb	kg	lb	kg
Sidewall				
Basic Panels	91.9	41.7	91.9	41.7
Reinforcement	26.5	12.0	33.1	15.0
Pans	91.0	41.3	91.0	41.3
Misc. Potting	9.2	4.2	9.2	4.2
Skin Tolerance	3.8	1.7	3.8	1.7
Latch Longerons	41.0	18.6	41.0	18.6
Frames and Rings				
Fwd, X_0 1172.9	13.0	5.9	13.0	5.9
Kick, X_0 1197.3	42.9	19.5	42.9	19.5
Stab., X_0 1221.6	9.8	4.4	9.8	4.4
Aft, X_0 1246	42.9	19.5	58.9	26.7
Orbiter Support Fittings				
X (2)	43.2	19.6	-	-
X/Z (2)	-	-	86.3	39.2
Y	-	-	21.8	9.9
System Supports	37.0	16.8	37.0	16.8
Structure Sub-Total	452.2	205.3	539.7	245.0
Contingency	45.2	20.5	54.0	24.5
Structure Total	497.4	225.8	593.7	269.5
Mechanisms				
Latches (16)	170.0	77.2	170.0	77.2
Deployment	61.0	27.7	61.0	27.7
Docking	60.0	27.2	60.0	27.2
Adapter Total	788.4	357.9	884.7	401.7

4.2.3.6 Dynamic Analysis. The dynamic analysis was conducted in two steps: 1) a modal analysis of four support arrangements plus the forced response analysis of two of the four, and 2) modal and forced response analyses of two additional arrangements chosen in hopes of eliminating problems encountered in the first analyses.

Figure 4.2-54 provides a summary of the method and significant results of all dynamic analyses performed during the study. The simplified finite element model used mass

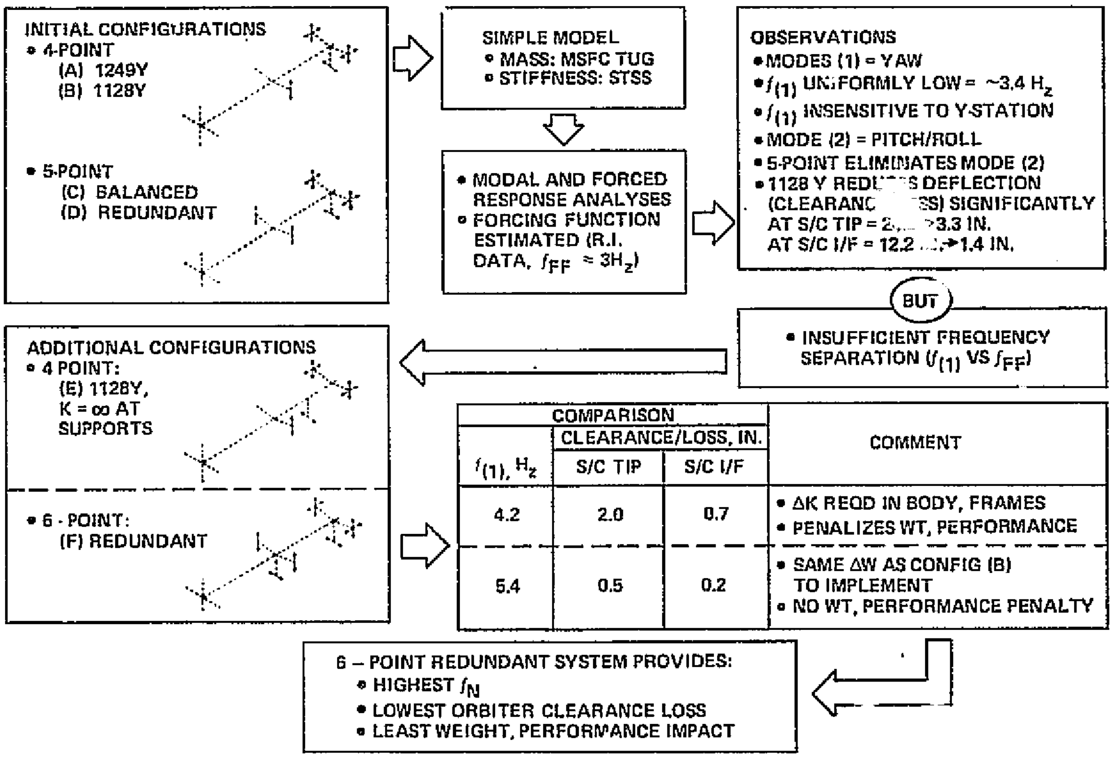


Figure 4.2-54. Dynamic Analysis Summary

properties for the MSFC Baseline Tug plus reference spacecraft in the deploy-ascent mission configuration. Figure 4.2-55 illustrates the geometry of the model and its mass properties are summarized in Table 4.2-28. The shells of the Tug and deploy adapter were modeled as a single beam located at the vehicle centerline. Directional springs representing the attachment structure and any local shell flexibility were attached to rigid arms extending to the outside of the shell at X_0 951 and 1246 (X_0 1128 for the intermediate Y-support case). The engine and the propellant tanks were considered rigid, attached to the shell by the proper spring stiffness representing the support strut system. Tug, adapter, and support stiffnesses were derived from finite element data generated from a detailed model during the Convair STSS. The stiffness of the 11,000 lb (4994 kg) reference spacecraft was assumed to be the same as the

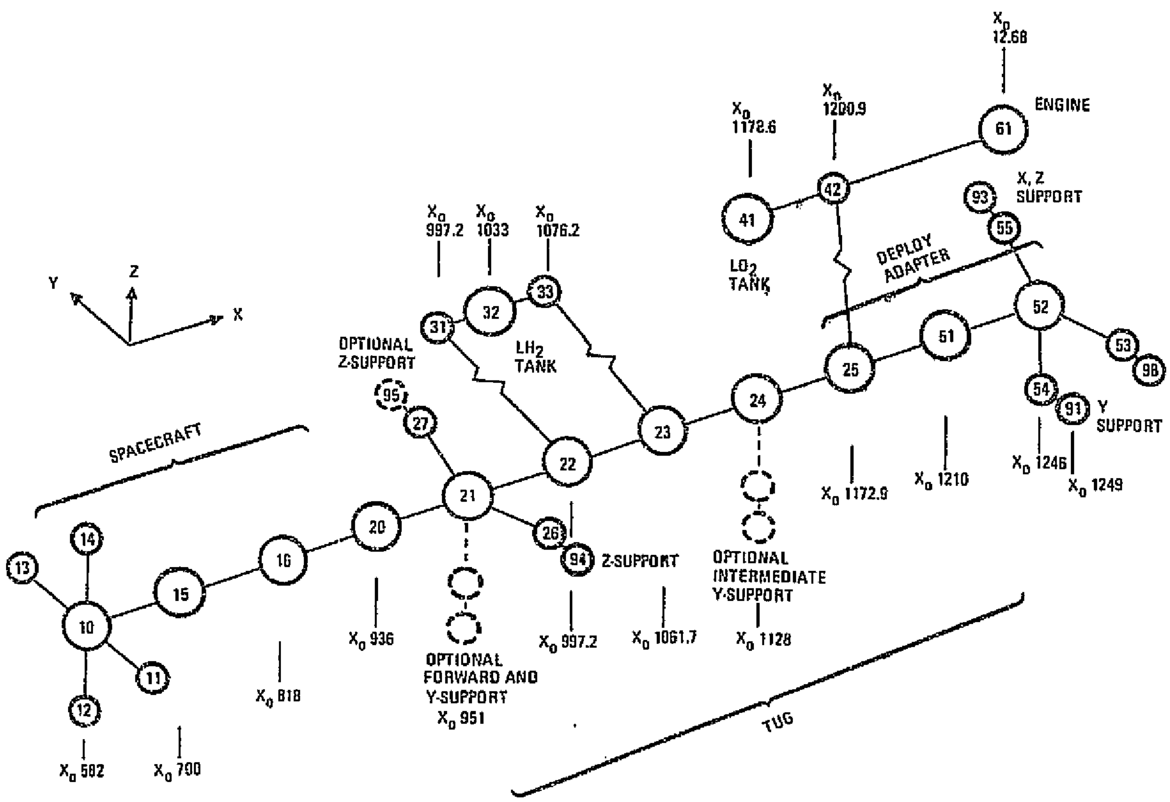


Figure 4.2-55. Tug Dynamic Model

forward end of the Tug. The tank weights included 6694 lb (3039 kg) of LH_2 and 39,188 lb (17,791 kg) of LO_2.

Initially, mode shapes and natural frequencies were determined for the following four support configurations (A through D in Figure 4.2-54):

a. Four-point determinate system with the Y-support at X_0 1249.

b. Four-point determinate system with the Y-support at X_0 1128.

c. Five-point load-balanced system with dual forward Z supports.

d. Five-point redundant system with dual forward Z supports.

All four exhibited a first mode frequency of ~3.4 Hz in the yaw plane as shown in Figure 4.2-56. Comparing the first two arrangements, it was found that moving the Y-support from station 1249 to station 1128 had little effect on this frequency. The second mode was a combined roll-pitch mode with a frequency of 4.3 Hz and the 5.4 to 5.6 Hz third mode, seen in all configurations, was a second bending mode in the X-Y (yaw) plane. It was also noted that only minimal difference in natural frequency occurred between the load balanced and redundant systems.

Table 4.2-28. Dynamic Model Mass Properties

Node	Weight		Moment of Inertia			
			I_x		I_y, I_z	
	lb	kg	10^6 lb-in.^{2}	10^2 kg-m^2	10^6 lb-in.^{2}	10^2 kg-m^2
10	643	292	2.40	7.29	0.00	0.00
15	3512	1594	13.60	39.83	0.00	0.00
16	4562	2071	17.70	51.84	0.00	0.00
20	2491	1131	9.71	28.44	0.77	2.26
21	706	321	2.94	8.61	2.61	7.64
22	357	162	1.49	8.36	1.32	3.87
23	371	168	1.54	4.51	1.37	4.01
24	1011	459	4.21	17.33	3.73	10.93
25	580	263	2.90	8.49	2.13	6.24
32	7744	3516	4.37	12.80	6.70	19.62
41	40372	18329	4.93	14.44	21.00	61.51
61	426	193	1.77	5.18	1.57	4.60
51	335	152	2.58	7.56	1.21	3.54
52	240	109	1.85	5.42	0.86	2.52

The first two modes occurred close to the fundamental driving frequency of the Orbiter (2 to 3 Hz) and were therefore expected to present problems because of the large amplification of the response when the vehicle was subjected to the Orbiter interface excitation. By adding a second Z support at X_o 951, either with or without the load balancing system, as shown for the latter two arrangements, the second mode (roll-pitch) was eliminated. However the low first frequency mode remained. To determine how much amplification would result because of these two low frequency modes, a transient response analysis was performed for the four-point 1249Y configuration. This was accomplished by equating the accelerations at the Orbiter support nodes (nodes 91 through 94) to the acceleration expected during the liftoff condition, since this condition produced the largest Y and Z loads on the fully tanked Tug (based on the JSC 07700 accelerations). All supports in a particular direction were assumed to receive the same acceleration from the Orbiter.

SUPPORT CONFIGURATION X_0 = 582 951 1246/1249	MODAL FREQUENCIES (Hz) ①	②	③	④
(A) 4-POINT, 1249Y	3.33	4.22	5.65	6.10
(B) 4-POINT, 1128Y	3.46	4.40	5.38	6.11
(C) 5-POINT, BALANCED	3.36	–	5.57	5.99
(D) 5-POINT, REDUNDANT	3.39	–	5.63	5.99

MODE SHAPES

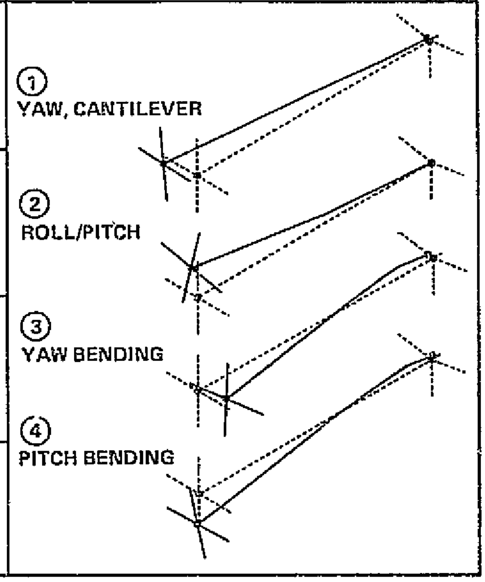


Figure 4.2-56. Modal Analysis Summary Systems A-D

The Orbiter time history traces were derived from Rockwell International data (RI/SD chart 64SSV21628B), as shown in Figure 4.2-57. Time histories at the X and Z supports were taken directly from the RI data. The Y-support acceleration time history was created from the Z-support curve (i.e., was assumed to be in phase with the Z support acceleration), but the peak value was scaled down by the ratio of the corresponding accelerations for the liftoff condition in the JSC 07700 accelerations (reference Table 4.2-2).

The forced response analysis of the four-point, 1249Y configuration indicated very large Y deflections (loss of Orbiter clearance) at the spacecraft tip (24.2 in.; 60.5 cm) and at the Tug/spacecraft interface (12.2 in.; 30.5 cm), as shown in Figure 4.2-58 and Table 4.2-29, which were due primarily to excitation of the fundamental mode of vibration. Similar analysis of the four-point, 1128Y configuration resulted in significant reduction in the Y deflections (to 3.3 in. (8.25 cm) and 1.4 in. (3.5 cm), respectively) as shown in Table 4.2-30. However, although these displacements were marginally acceptable; they represented centerline deflections only and did not include allowance for Tug shell noncircularity due to frame distortion, which is particularly significant at the Tug/spacecraft interface (X_0 936, node 20) due to the influence of the nearby Orbiter support frame. Furthermore, the low first mode frequency provided insufficient frequency separation from the forcing function since both the frequency content and amplitude of the current appropriate forcing function are not known.

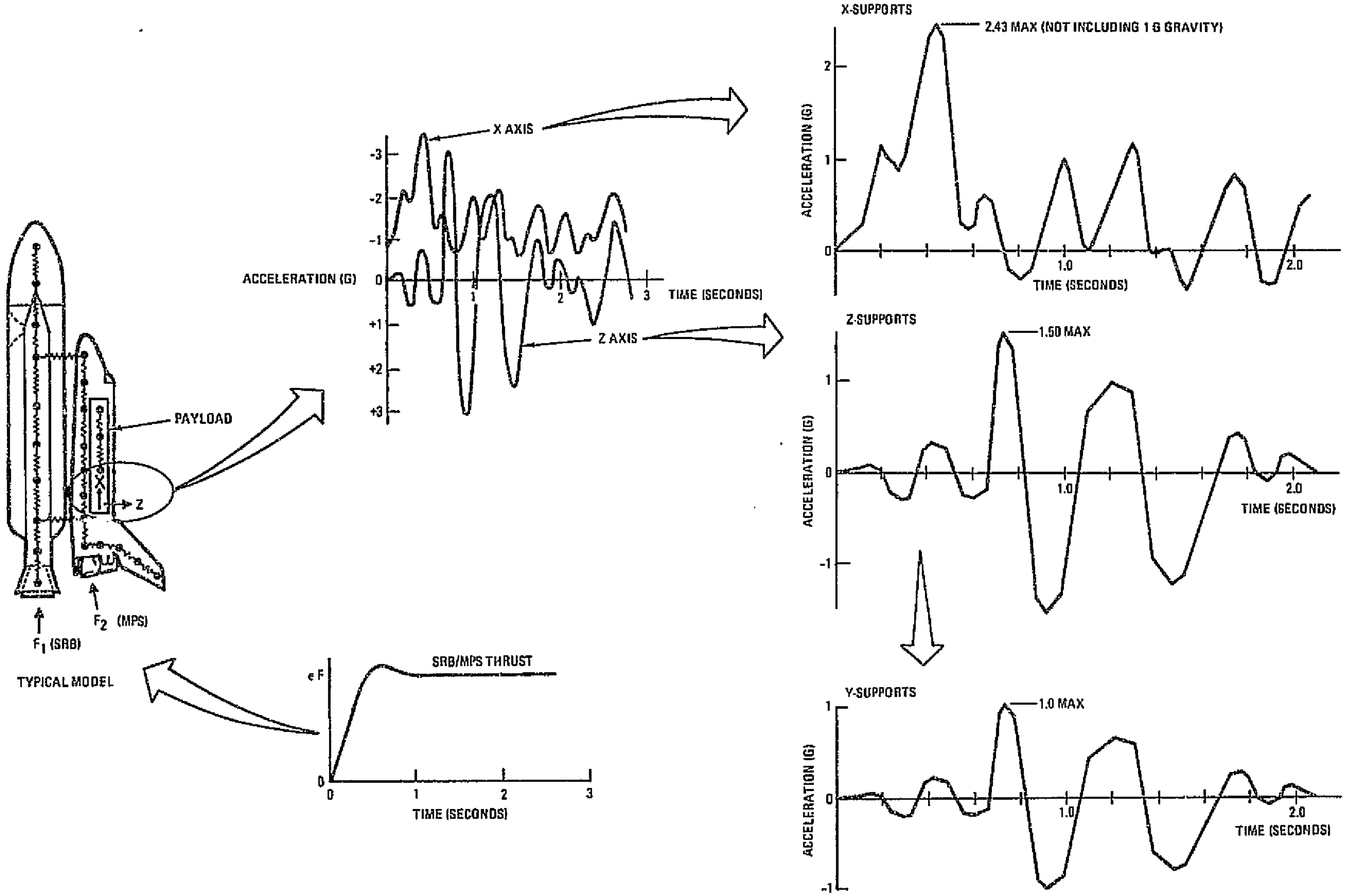


Figure 4.2-57. Derivation of Orbiter Acceleration Time Histories

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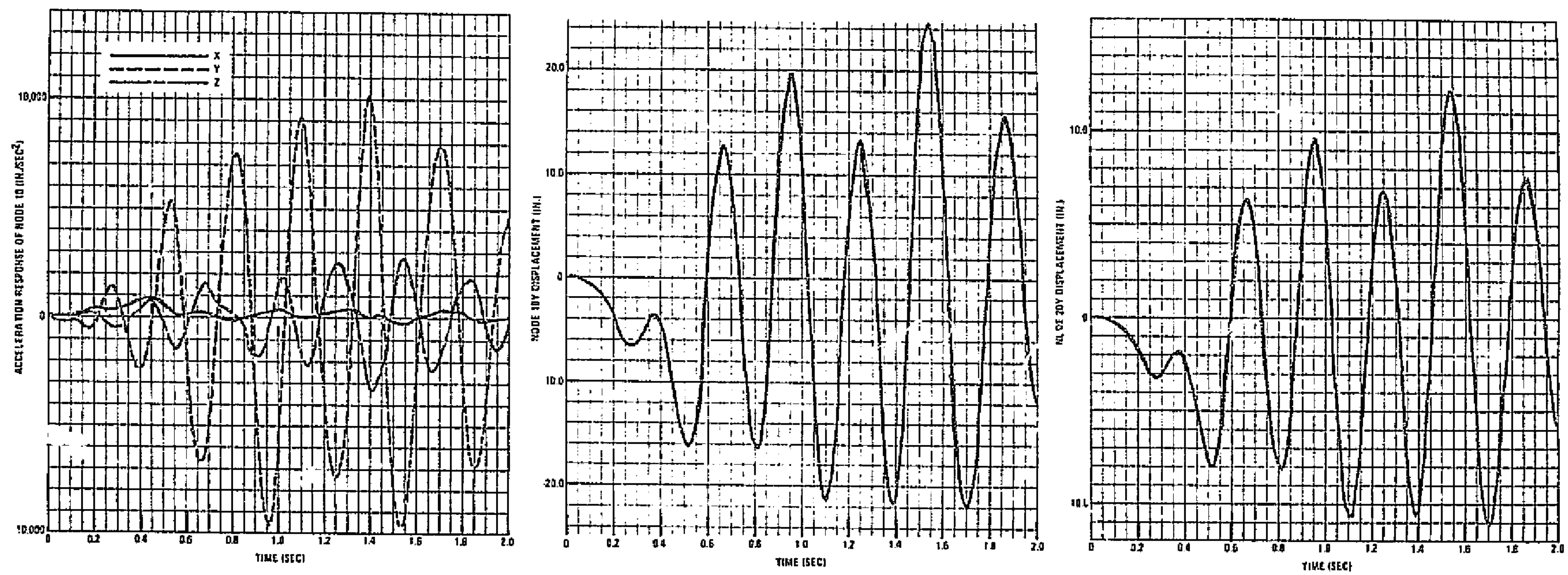


Figure 4.2-58. Response at Selected Nodes, System A

Table 4.2-29. Response Analysis Summary, System A

Response	Node	Direction		
		X(1)	Y	Z
Acceleration, g	10	3.40	26.4	8.5
	20	3.40	12.4	3.7
	25	3.40	4.9	2.1
	52	3.40	2.9	1.6
	32	3.40	9.5	3.2
	41	3.40	6.0	2.8
	91	-	1.0	-
	92	3.43	-	1.5
	93	3.43	-	1.5
	94	-	-	1.5
Displacement(2) in. (cm)	10	0.14 (0.36)	24.2 (61.5)	6.4 (16.3)
	20	0.14 (0.36)	12.2 (31.0)	2.3 (5.8)
	27	2.40 (6.10)	12.0 (30.5)	3.9 (9.9)

Notes: (1) X acceleration response includes gravity.
(2) Displacements measured relative to Orbiter.

It was therefore concluded that the best way to obtain acceptable response was to eliminate or increase the mode at 3.3 Hz to above 5 Hz by providing either additional stiffness or additional bending constraints in the Y direction. Consequently, two additional support configurations were assessed with the objective of increasing first mode frequency and thereby further reducing displacement response. System E was geometrically identical to B but incorporated infinite stiffness at all support points, since examination of previous response data indicated support softness as a major contributor to response. This implied a substantial weight increase relative to System B, from which it evolved, to provide increased fitting, frame, and body stiffness. Tug performance would be penalized as a result. System F was similar to D but added a second Y-support, at X_0 951. Relative to System B, the delta weight, delta performance impacts of F were approximately zero due to the need for a major support frame plus a relocated Y-fitting on the Tug in B, whereas F adds both a Y and a Z fitting to the Tug but requires only local beef-up of the existing X_0 951 support frame.

Comparison of Systems E and F in Figure 4.2-59 and Tables 4.2-31 and 4.2-32 indicated increased first-mode frequency and reduced displacement response in each, but F exhibited a distinct advantage in both categories and was therefore recommended since it also resulted in the least weight/performance impact.

Table 4.2-30. Response Analysis Summary, System B

Response	Node	Direction		
		X(1)	Y	Z
Acceleration, g	10	3.43	4.79	6.10
	20	3.42	2.44	2.57
	25	3.42	1.91	2.10
	52	3.41	2.01	1.57
	32	3.40	2.04	2.42
	41	3.43	2.65	2.71
	91	-	1.00	-
	92	3.43	-	1.50
	93	3.43	-	1.50
	94	-	-	1.50
Displacement(2), in. (cm)	10	0.06 (0.15)	3.27 (8.31)	2.71 (6.88)
	20	0.06 (0.15)	1.39 (3.53)	0.80 (2.03)
	21	0.06 (0.15)	1.30 (3.30)	0.71 (1.80)
	27	0.35 (0.89)	1.25 (3.20)	1.18 (3.00)
	24	0.06 (0.15)	0.50 (1.27)	0.59 (1.50)
	52	0.06 (0.15)	0.69 (1.75)	0.11 (0.28)

Notes: (1) X acceleration response includes gravity.
(2) Displacement measured relative to Orbiter.

SUPPORT CONFIGURATION	MODAL FREQUENCIES (Hz)(1)			
X_o = 582 951 1246/1249	①	②	③	④
(E) 4-POINT, 1128Y (K = ∞ AT SUPPORTS)	4.20	4.89	6.40	6.73
(F) 6-POINT, REDUNDANT	5.41	—	6.54	5.09

(1) MODE NUMBERS, SHAPES PER FIGURE 4.2-56.

Figure 4.2-59. Modal Analysis Summary, Systems E and F

4.2.3.7 Alternative X/Z Support. In Section 4.2.2.2 it was shown that Tug support reactions exceed Orbiter capability, using both MSFC 68M00039-1 and JSC 07700 accelerations in all support arrangements employing existing Orbiter provisions. To improve understanding of the Tug reaction exceedance problem, a meeting was held at which the Convair presentation pointed out that the general payload guidelines (not published requirements) used for developing Orbiter support capability were not consistent with real-world Tug physical requirements and that

Table 4.2-31. Response Analysis Summary, System E

Response	Node	Direction $X^{(1)}$	Y	Z
Acceleration, g	10	3.50	3.92	4.08
	20	3.46	1.90	2.31
	25	3.40	1.38	1.84
	52	3.40	1.39	1.50
	32	3.64	1.48	2.16
	41	3.45	1.90	2.49
	91	-	1.00	-
	92	3.43	-	1.50
	93	3.43	-	1.50
	94	-	-	1.50
Displacement$^{(2)}$, in. (cm)	10	0.10 (0.25)	2.04 (5.18)	1.96 (4.98)
	20	0.08 (0.20)	0.66 (1.68)	0.51 (1.30)
	21	0.07 (0.18)	0.60 (1.52)	0.44 (1.12)
	27	0.24 (0.61)	0.53 (1.35)	0.89 (2.26)
	24	0.05 (0.13)	0.10 (0.25)	0.36 (0.91)
	52	0.04 (0.10)	0.23 (0.58)	0.00 (0.00)

Notes: (1) X acceleration response includes gravity.
(2) Displacement measured relative to Orbiter.

this was the cause of our reaction exceedance. The proposed solution consisted of moving the Tug aft X/Z supports to X_o 1269.6, where new Orbiter bridge beam and trunnion were required. Presented here are the features and effects on the Tug of the alternative X/Z support location. Subsequent analyses using still later acceleration data (Section 4.2.3.8) resulted in acceptable support reactions. Consequently the alternative X/Z support concept discussed here was not required for the preferred support arrangement.

Tug/Orbiter Compatibility Assessment. The presence of reaction exceedances obtained for such a wide range of Tug support arrangements raised questions as to the Orbiter/payload accommodations structural design approach. Therefore an investigation was conducted to determine the apparent characteristics of the payloads used for developing Orbiter capability and the associated guidelines and constraints employed.

The structural accommodations in the Orbiter cargo bay had to encompass a very broad range of potential payloads. Included were single, large payloads, and as many

Table 4.2-32. Response Analysis Summary, System F

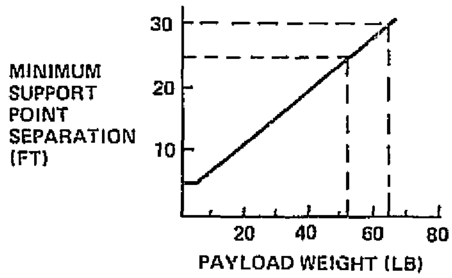
Response	Node	Direction X(1)	Y	Z
Acceleration, g	10	3.55	2.08	3.44
	20	3.53	1.20	1.66
	25	3.50	1.78	2.03
	52	3.46	1.43	1.59
	32	3.65	1.27	2.01
	41	3.52	1.83	2.80
	91	-	1.00	-
	92	3.43	-	1.50
	93	3.43	-	1.50
	94	-	-	1.50
	95	-	-	1.50
	96	-	1.00	-
Displacement(2), in. (cm)	10	0.17 (0.43)	0.52 (1.32)	0.87 (2.21)
	20	0.16 (0.41)	0.20 (0.51)	0.14 (0.36)
	21	0.16 (0.41)	0.19 (0.48)	0.10 (0.25)
	24	0.12 (0.30)	0.48 (1.22)	0.37 (0.94)
	52	0.08 (0.20)	0.31 (0.79)	0.11 (0.28)

Notes: (1) X acceleration response includes gravity.
(2) Displacement measured relative to Orbiter.

as five individually supported multiple payloads. To account for the full spectrum of possible support combinations, and to design the Orbiter midbody to structurally accept the resulting reactions, a fairly complex computer program was employed to perform the parametric analysis. To suitably bound this immense task, ground rules or guidelines were developed for use as constraints in the computation. The more significant of these guidelines are shown in Figure 4.2-60. Unfortunately, the bounding conditions apply to relatively inert cargo rather than to relatively active systems such as Tug plus spacecraft. The CG constraints and Y fitting placement guideline are excellent examples. In addition, this Orbiter capability development process was performed before the long-payload influence on Tug length which resulted in a shorter baseline Tug configuration. For this reason, the MSFC 30-foot (9.1 m) long baseline Tug, designed to take full performance advantage of the Orbiter 65k lb cargo limit, was physically limited by available Orbiter support fitting locations to a 24.5-foot (7.47 m) span between supports and, apparently, to a corresponding 52k lb (23.6×10^3 kg) gross weight.

ORBITER-IMPOSED GUIDELINES FOR GENERALIZED PAYLOADS

- PAYLOADS MUST COMPLY WITH ALLOWABLE ORBITER CG LIMITS (PRESUMABLY AT ALL TIMES)
- PAYLOAD CG WITHIN 50 TO 70% OF PAYLOAD LENGTH

  PAYLOAD CG NOT CANTLIVERED OUTSIDE SUPPORT POINTS
- KEEL FITTING PLACED AT OR NEAR PAYLOAD CG
- 

SPACE TUG CHARACTERISTICS

- BASELINE TUG NORMALLY OPERATES WITH ITS CG AFT OF ORBITER ENVELOPE. LO_2 DUMP DURING ABORT PLACES CG BACK WITHIN LIMITS
- TUG PLUS PAYLOAD CG VARIES FROM 42 TO BEYOND 100% OF TUG LENGTH & DEPENDING ON FLIGHT CONDITION, MAY LIE EITHER BETWEEN OR CANTILEVERED BEYOND SUPPORTS.
- LARGE TUG PLUS PAYLOAD CG SHIFT DOES NOT SATISFY THIS REQUIREMENT FOR ANY SINGLE Y FITTING PLACEMENT
- BASELINE TUG IS 30 FT LONG OVERALL. MAXIMUM SEPARATION OF ORBITER FITTINGS SUITABLE FOR TUG ROTATIONAL DEPLOYMENT IS 24.5 FT

Figure 4.2-60. Tug/Orbiter Compatibility Assessment

Bridge Beam Concept. It was found that all reaction exceedance due to JSC accelerations could be eliminated by using an alternative five-point (four-Z) support concept employing a new bridge beam that provided primary X/Z support aft of X_o 1246. A configuration concept for the new bridge beam and the evolution of the selected trunnion location are shown in Figure 4.2-61. Initially the trunnion was located at X_o 1260 to minimize the support adapter length increase while maintaining adequate engine bell clearance from the cargo bay aft limit (X_o 1302) during rotation. However, this location was found to be unacceptable due to interference with an RMS latch and a cargo bay door hinge; consequently the forward most acceptable location, X_o 1269.6, was chosen.

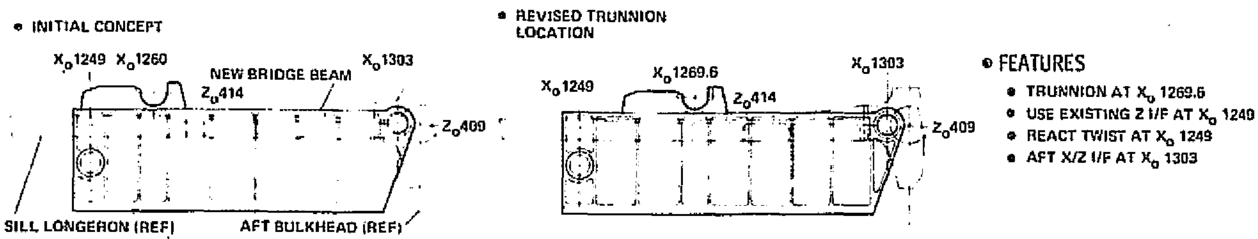


Figure 4.2-61. Bridge Beam Concept for Alternative Aft Support Location

The new beam spans from the X_o 1249 mid-fuselage frame to the longeron/bulkhead joint region at X_o 1303. The existing beam/frame Z-load and twist restraint interfaces at X_o 1249 are unchanged. Drag (X) loads are carried aft by the bridge beam and introduced to the Orbiter primary structure at X_o 1303, avoiding drag load application to the sill longerons.

Support Reactions. The support reactions and resulting exceedance are given in Figure 4.2-62 for support arrangements 1-1 and 2-1, with the Y support relocated to

SUPPORT REACTIONS (1)												
SUPPORT CONFIG	X_1 & X_2 +	X_1 & X_2 -	Y_1 ±	Z_1 +	Z_1 -	Z_2 +	Z_2 -	Z_3 +	Z_3 -	Z_4 +	Z_4 -
1-1 (4-POINT)	127.4	65.2	64.6	81.0	81.0	49.2	40.8	56.3	75.9	–	–
2-1 (5-POINT)	127.4	65.2	64.6	60.0	56.[illegible]	60.0	56.2	28.2	38.0	28.2	38.0
LOCATION, X_o	1269.6		1181	1269.6		1269.6		951		951	
ORB CAPABIL.	TBD	TBD	67.0	122.0	89.9	122.0	89.9	52.0	67.0	52.0	67.0

ACCUMULATED EXCEEDANCE		
SOURCE	1-1	2-1
X ONLY	0	0
X IN X/Z	TBD	TBD
Y	0	0
Z ONLY	13.2	0
Z IN X/Z	0	0
Σ	13.2	0

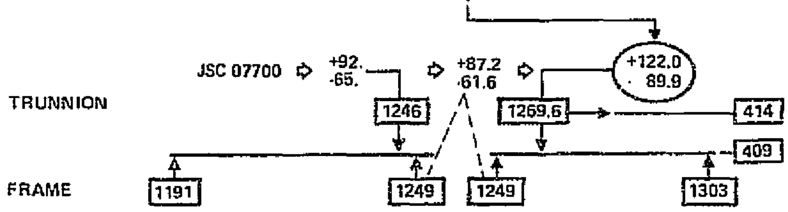


Figure 4.2-62. Support Reactions and Orbiter Capability Determination .or X_o 1269.6 X/Z Support

X_o 1181, using JSC accelerations. A slight exceedance is noted for configuration 1-1, whereas configuration 2-1 is entirely within Orbiter capability. See Table 4.2-5 for previous exceedance using X_o 1246 X/Z supports. Sufficient Orbiter capability was anticipated at X_o 1303 due to redesign to provide the bridge beam aft interface, and the apparent capability for X_o 1269.6 X/Z loading was conservatively derived as shown by assuming that maximum X and Z reactions occurred simultaneously.

Tug Effects. Tug effects associated with the proposed support concept are shown in Figure 4.2-63. The deployment adapter had to be lengthened 23.6 in. (59 cm) to align the aft interface frame with the new trunnion location. No Y-support provisions exist at X_o 1269.6, but the existing X_o 1249, X_o 1181, and X_o 1128 locations were still candidates. Of the three, X_o 1181 was preferred since a frame at this station could also react the yaw kick loads in the X fittings and support the Tug/adapter separation alignment guides. Deletion of the X_o 1249 main Y-support eliminated the X-reaction

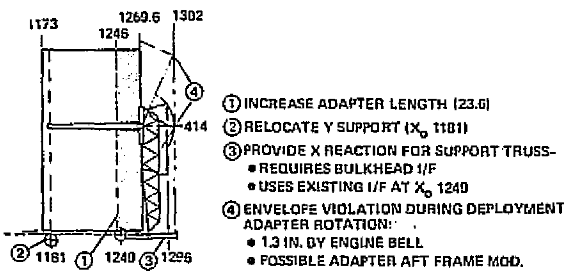


Figure 4.2-63. Effects on the Tug of X_o 1269 X/Z Support

for the umbilical panel support truss. Consequently, a lightweight link was required, which spanned from the existing brackets on the X_o 1249 frame to the cargo bay aft bulkhead where a new attachment bracket was required. During rotation with the baseline Tug engine bell exit plane (X_o 1296), the cargo bay envelope was violated a maximum 1.3 in. (3.25 cm) by the engine. A suitable deployment adapter aft frame modification would have precluded any adapter interference, but the engine bell encroachment of Orbiter space was expected to be permissible since both Tug and Orbiter were unloaded at this time, and therefore neither was deflected from nominal configuration.

4.2.3.8 Support Reaction Analysis Update. The objectives of the support reaction analysis update were threefold: 1) to recompute the support reactions for the candidate systems using the latest MSFC accelerations specified in MSFC PF-02-75-31, and to determine the extent of any Orbiter support capability exceedance; 2) to assess the effects of crash loads in terms of Orbiter support capability exceedance and Tug impact, and 3) to support the assessment of Y-support station location effects. The support arrangements involved in the update analyses were those shown in Figure 4.2-64.

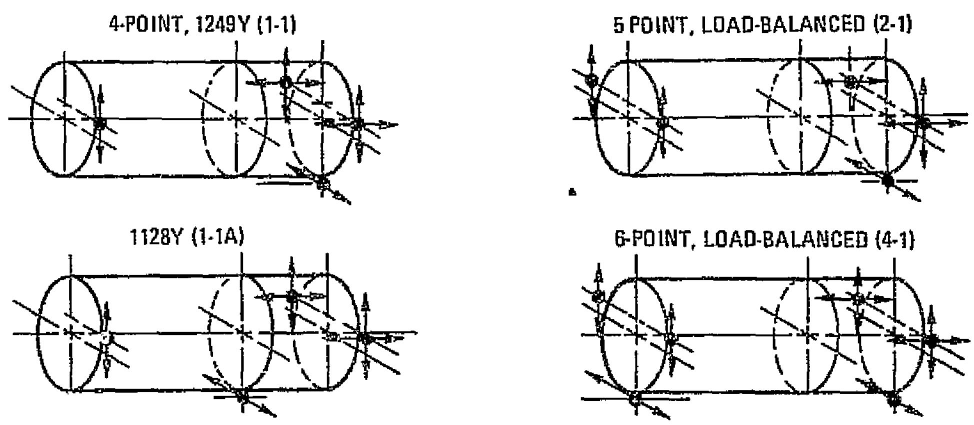


Figure 4.2-64. Candidate Support Arrangements

The four-point system with its Y-support at X_o 1249 (support arrangement 1-1) and the five-point load-balanced system were recommended after the initial screening, and a preference for the latter system was indicated at the major study review. However, in response to the concern over yaw dynamic softness (Section 4.2.3.6), the six-point (dual-Y) load-balanced system (4-1) and the four-point X_o 1128 Y system (1-1A) were

C-4

added. The two initially recommended support arrangements without support adapter (1-2 and 2-2) were deleted in the meantime due to communications, RMS deployment, and weight/performance considerations. Table 4.2-33 summarizes the specific support point locations in the candidate systems.

Table 4.2-33. Support Locations in Candidate Arrangements

System	Support Point Stations, X_0					
	X_1, X_2	Y_1	Y_2	Z_1, Z_2	Z_3	Z_4
4-Point						
1249 Y (1-1)	1246	1249	-	1246	951	-
1128 Y (1-1A)	1246	1128	-	1246	951	-
5-Point						
Balanced (2-1)	1246	1249	-	1246	951	951
6-Point						
Balanced (4-1)	1246	1249	951	1246	951	951

<u>Support Reaction Recomputation.</u> The following ground rules were used in this task:

a. Mass properties for the descent and landing case assumed both propellant tanks empty. Previous support reaction analyses assumed a full fuel tank since the MSFC baseline Tug did not initially have sub-orbital (RTLS abort) LH_2 dump.

b. Crash reactions were excluded here and addressed in the following subsection.

c. The Y-support was located at Orbiter Station X_0 1249. Variation of Y-support support station is addressed in a later subsection.

d. Redundant systems are excluded here but are addressed in Section 4.2.3.9.

Support reactions were computed for each load case given in MSFC PF-02-75-31 including all possible perturbations and combinations of signs using the computer program previously illustrated in Figure 4.2-18. The results are shown in Figure 4.2-65. The tabular data defines the positive and negative maximum values at each support location and the X/Z interaction plots define the envelopes of all X/Z reaction pairs at the aft supports for each mission phase in each support system. To generate the X/Z envelopes, the program above was modified to plot each X/Z pair for each individual acceleration case. The interaction plots indicate that the four-point and five-point systems both experience excessive reactions in the X-direction only, whereas all X/Z

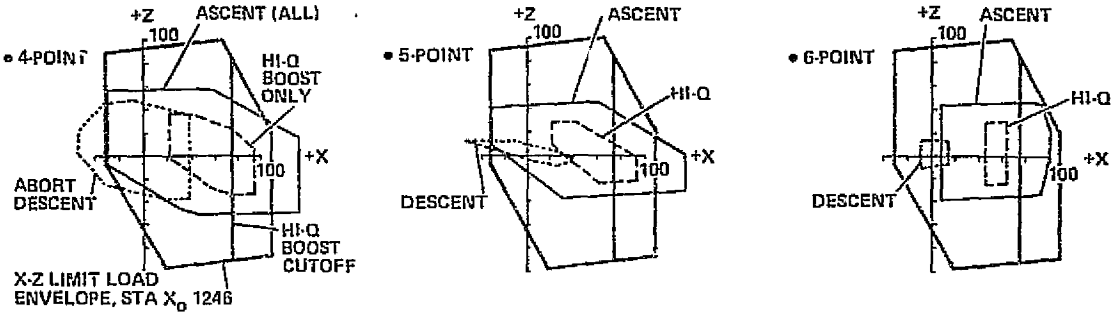
- SUPPORT REACTIONS
  - EXCLUDING CRASH
  - BOTH TANKS EMPTY DURING ABORT DESCENT
  - Y-SUPPORT AT X_0 1249

CONFIG	REACTIONS (1,000 LB) X_1 & X_2 +	X_1 & X_2 –	Y_1 ±	Y_2 ±	Z_1 +	Z_1 –	Z_2 +	Z_2 –	Z_3 +	Z_3 –	Z_4 +	Z_4 –
4-POINT	133.1	53.8	45.2	–	57.5	51.1	47.3	28.0	38.1	71.0	–	–
5-POINT	133.1	53.8	45.2	–	45.2	37.0	45.2	37.0	19.1	35.5	19.1	35.5
6-POINT	100.5	9.9	27.1	28.3	45.9	37.7	45.9	37.7	19.1	35.5	19.1	35.5
ORBITER CAPABILITY	*	*	56.0	70.0	*	*	*	*	52.0	67.0	52.0	67.0

*X/Z INTERACTION, SEE BELOW FOR EACH SUPPORT CONFIGURATION

- EXCEEDANCE COMPARISON (1)

CONFIG	ACCELERATIONS PER MSFC PF-02-75-31	MSFC 68M00039-1	JSC 07700 "C"
4-POINT	93.8	344.9	179.7
5-POINT	89.8	193.4	155.6
6-POINT	0	266.0	0



(1) EXCEEDANCES PER MSFC 68M00039-1 AND JSC 07700 "C" RECOMPUTED AS NECESSARY TO REFLECT GROUND RULE UPDATE TO DUMP FUEL PRIOR TO ABORT DESCENT

Figure 4.2-65. Support Reaction Recomputation and Exceedance Comparison

interaction in the six-point system is within Orbiter capability. This is shown numerically in the exceedance comparison table. The difference between the four and five-point systems results from a small exceedance at the $-Z_3$ reaction in the four-point system. Reactions in the six-point system are all within Orbiter capability.

The current accelerations result in exceedance significantly lower than that computed for previous acceleration sets. For this comparison the exceedance totals using accelerations per MSFC 68M00039-1 and JSC 07700, Vol. XIV, Rev. C were recalculated as necessary to reflect fuel dump before abort descent.

Crash Load Effects. All previous support reaction exceedance assessment has been based on comparisons of computed support reactions with Orbiter limit capability as specified in JSC 07700, Vol. XIV, Rev. C. No indication was given there as to which Orbiter structural elements (payload support fittings or mid-fuselage basic structure) were critical in defining limit capability. Since crash loads are ultimate and are to be carried only through the bridge beam/mid-fuselage attachments on the Orbiter side, the Orbiter capability with respect to crash loads was not apparent. To evaluate the effect of crash loads within the available capability data, the following approach was taken:

a. The bridge beam/mid-fuselage interface was assumed to be critical for all existing limit load capability data.

b. A "quasi-limit" crash load case was defined. Accelerations were as specified in JSC 07700 includ'ng a 20-degree cone on the 9.0-g X-accelerations. Mass properties for th Tug (both propellant tanks empty) plus spacecraft were revised to reflect an "eff ctive" weight equal to the true weight reduced by the ultimate factor of safety (1.4).

The resulting aft X, Z support reactions are shown in the interaction plot in Figure 4.2-66, while the Y and forward Z reactions are tabulated. The tabular data emphasizes those reactions in each support system whose maxima are produced by the "quasi-limit" crash case. None of these crash reactions exceeded Orbiter capability.

- CRASH LOAD EFFECTS
  - BOTH TANKS EMPTY
  - Y-SUPPORT AT X_o1249
  - "QUASI-LIMIT" LOAD CASE:
    - JSC 07700 "C" ACCEL
    - $W_{EFFECTIVE} = W_{TOTAL}/1.4$

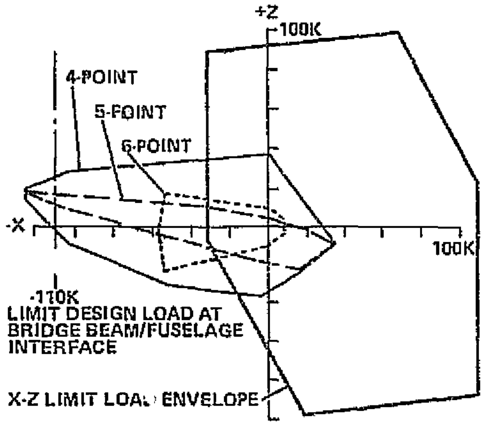
- Y, FWD Z REACTIONS

CONFIG	INCL CRASH?	REACTIONS (1,000 LB) Y_1 ±	Y_2 ±	Z_3 +	Z_3 −	Z_4 +	Z_4 −
4-POINT	NO	45.2	–	38.1	71.0	–	–
	YES	45.2	–	49.6	71.0	–	–
5-POINT	NO	45.2	–	19.1	35.5	19.1	35.5
	YES	45.2	–	24.8	35.5	24.8	35.5
6-POINT	NO	27.1	28.3	19.1	35.5	19.1	35.5
	YES	27.1	44.4	24.8	35.5	24.8	35.5
ORBITER CAPABILITY		56.0	70.0	52.0	67.0	52.0	67.0

- EXCEEDANCE COMPARISON

CONFIG	INCL CRASH? NO	YES
4-POINT	93.8	235.2
5-POINT	89.8	231.2
6-POINT	0	51.2

- X/Z INTERACTION AT X_o 1246



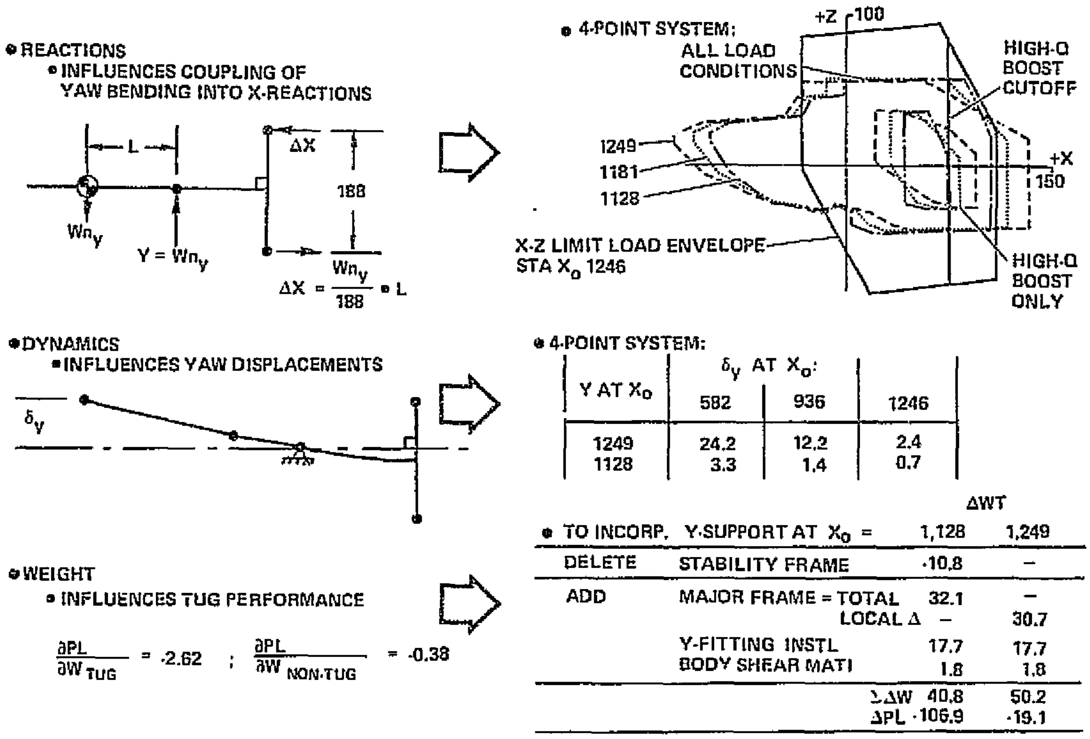
- TUG IMPACTS
  - 4-POINT: NONE
  - 5-POINT: NONE
  - 6-POINT: DESIGNS FWD Y FITTING, ATTACHMENTS

Figure 4.2-66. Crash Load Effects

The interaction plot exhibits substantial excess in the negative X reactions, particularly in the four- and five-point systems. However, recent information indicated a 110 klb (489 kN) limit design load at the bridge beam/mid-fuselage interface. As shown, reactions in the four- and five-point systems still exceeded this value, but those for the six-point system were well within it. The exceedance comparison numerically illustrates the crash reaction versus Orbiter capability situation. Crash reactions increased the exceedance in all systems relative to current JSC 07700 capability, but adoption of the 110k lb (489 kN) capability, if appropriate, eliminated exceedance in the six-point system.

Crash load effects on Tug design were negligible. In the four- and five-point systems, the maximum crash reaction at each point was exceeded by a reaction in another mission phase, hence there was no impact. In the six-point system, the forward Y fitting experienced a higher maximum load during crash, resulting in a weight penalty of approximately five lb (2.25 kg) in the fitting itself. No frame or body weight penalty occurred since these elements were not required to be designed for crash loads.

Effects of Y-Support Location. The station location of the Y support in single Y (i.e., four-point and five-point) systems was of importance since it influenced the interface impacts to Tug and Orbiter in three ways: reactions, dynamics, and weight. These are illustrated in Figure 4.2-67.



Y AT X_o	δ_y AT X_o: 582	936	1246
1249	24.2	12.2	2.4
1128	3.3	1.4	0.7

• TO INCORP.	Y-SUPPORT AT X_o =	ΔWT 1,128	1,249
DELETE	STABILITY FRAME	-10.8	–
ADD	MAJOR FRAME = TOTAL	32.1	–
	LOCAL Δ	–	30.7
	Y-FITTING INSTL	17.7	17.7
	BODY SHEAR MATL	1.8	1.8
	ΣΔW	40.8	50.2
	ΔPL	-106.9	-19.1

Figure 4.2-67. Effects of Y-Support Location

From the point of view of support reactions, the best Y-support location was at the vehicle longitudinal CG, since this eliminated coupling of yaw bending into the X reactions. As illustrated, any offset, L, between the Y-support station and the CG resulted in an incremental X-reaction change, ΔX, which was a linear function of L. Unfortunately, the Tug does not have a fixed CG location for all mission types and phases. During the ascent phase the CG can lie anywhere within a 79-in. (197.5 cm) bandwidth (X_O 1089-1148), depending on mission type (deploy or retrieve) and deploy spacecraft weight. In addition, during abort descent with the reference (heaviest

cantilevered) spacecraft, the CG lies 175 in. (4 .5 cm) forward of the ascent band (reference Section 4.2.2.2, Figure 4.2-19). Consequently, there was no optimum CG location, although station X_0 1128 was the best choice among the three available locations as shown in the X/Z interaction comparison. It provided +X reactions within both the overall and hi-q boost envelopes and exhibited the least exceedance for -X reactions.

Considering dynamic response (reference Section 4.2.3.6), yaw displacements (δ_y) from the nominal vehicle centerline were reduced as shown by judicious selection of Y-support station. Again X_0 1128 provided a substantial decrease in all yaw displacement as indicated in the comparison of forced response data for two otherwise identical four-point systems. The three reference stations presented are the forwardmost spacecraft tip station (X_0 582), the Tug/spacecraft interface (X_0 936), and the aft Tug/Orbiter interface (X_0 1246).

The choice of Y-support station was not clearcut, however, since the allocation of weight between the Tug flight vehicle and its Orbiter-retained deployment adapter strongly influenced payload deployment capability to synchronous orbit, as shown by the ~7:1 ratio between payload penalty partials. Assuming a vehicle initially lacking a Y support, the weight and performance penalties to incorporate the support at either of two possible locations (X_0 1128 or 1249) are shown. The performance advantage clearly lies with the X_0 1249 location. Consequently, the final choice of a best Y support location depended on the relative importance assigned to the various influencing considerations. It was for this reason that two four-point systems, with different Y-support locations, were included in the subsequent weight/performance evaluation of candidate support systems (Section 4.2.3.10).

4.2.3.9 Redundant Support Analysis. Early analyses indicated that Tug support reactions exceeded Orbiter support point capability for Tug configurations using the baseline four-point support concept. In addition, large dynamic loads and deflections were produced in the Tug body for the baseline four-point support system.

To reduce Tug support reactions as well as Tug dynamic loads and deflections, several alternate support concepts using additional support points were considered. Without special load balancing provisions to decouple the supports these alternate concepts are all statically indeterminate. For these redundant support concepts, Orbiter deflections will induce loads in the Tug structure. Misalignment and tolerance accumulations between the Tug/Orbiter redundant support points will also produce loads in the Tug body.

To establish feasibility of the redundant support concepts it was necessary to evaluate both of these effects.

Two redundant support concepts were considered. The first was a five-point system using, in addition to the Tug baseline four support points, a second forward Z support

at Station 951 (see Figure 4.2-68). With this concept, the Tug support system is statically determinate for all loading except torsional bending (Mx). This support concept eliminates the high torsional loading and deflection of the Tug body shell due to the eccentric forward Z support in the baseline four-point support concept. However, torsional loads and deflections are induced in the Tug body shell due to Orbiter twist and out-of-plane tolerance and mismatch of the four Z supports.

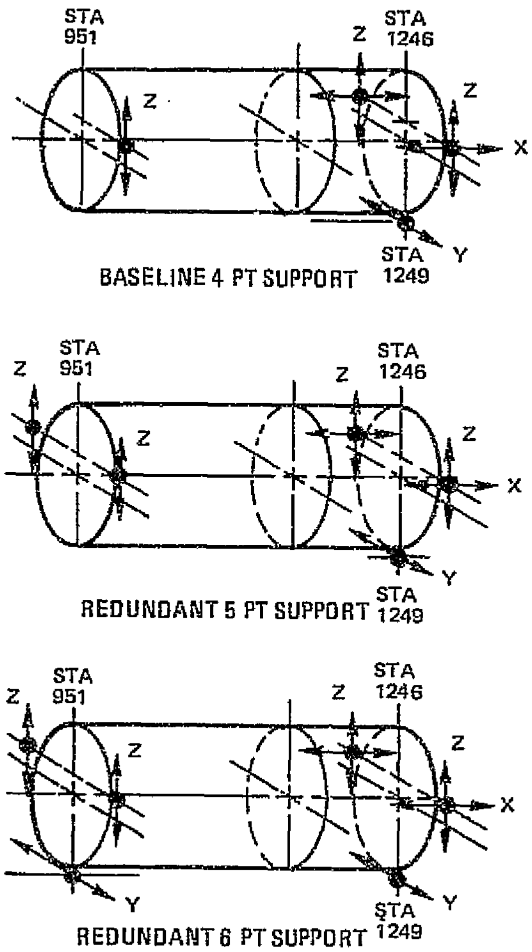


Figure 4.2-68. Tug Redundant Support Concepts

The second redundant support concept was a six-point system using a second forward Z support at Station 951 and a second Y support, also at Station 951 (see Figure 4.2-68). With this concept, the Tug support system is statically determinate for all loading except torsional bending (Mx) and yaw bending (Mz). This support concept also eliminates the high torsional loading and deflection of the Tug body shell due to the baseline four-point support concept. In addition, yaw deflections ($\pm\delta y$) are reduced.

Orbiter Load/Deflection Impact. With a redundant five- or six-point Tug support concept, Orbiter loads/deflections will induce loads in the Tug body structure. The magnitude of these induced Tug body loads is a function of the relative roll (Mx) and yaw (Mz) flexibility of the Tug and Orbiter.

To evaluate the impact of Orbiter loads and deflections on Tug body loads, the simplified computer finite element model shown in Figure 4.2-69 was generated using equivalent stiffnesses (Table 4.2-34) derived from the detailed Tug finite element model discussed in Section 4.2.3.1. Stiffnesses of the various model elements were adjusted until deflections matched those from the detailed finite element model. A Convair production structural analysis program, SOLID SAP, was used for the analysis. Mass properties used in the analysis are summarized in Table 4.2-35. Accelerations used in the analysis were the latest values supplied for the study (reference MSFC PF-02-75-31) except that the angular accelerations were not included. Load factors are summarized in Table 4.2-36.

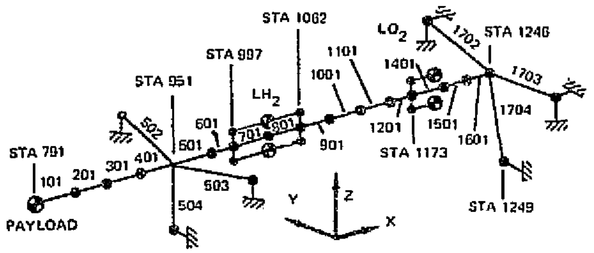


Figure 4.2-69. Redundant Support Analysis Computer Model

Specific critical load cases were selected based on anticipated maximum support reactions or maximum Orbiter deflections. Maximum Orbiter deflections were obtained from preliminary runs of the Rockwell International ASKA program analysis of the Orbiter mid-fuselage structure. Due to structural symmetry and the limited support redundancy the only Orbiter deflections that induce loads in the Tug body are the asymmetric roll (Mx) and relative yaw (Mz) deflections between Stations X_o 951 and X_o 1246.

Maximum relative twist between the Orbiter cargo bay sill longerons and the relative yaw deflection at the cargo bay bottom centerline between Station X_o 951 and X_o 1246 are presented in Table 4.2-37. Relative twist and relative yaw are defined in Figure 4.2-70. For the yaw conditions and Orbiter X-load, support points tend to deflect asymmetrically to reduce the yaw fixity. These deflections were conservatively ignored in the analysis (i.e., the Tug X supports were assumed built in).

The analysis approach consisted of:

a. Initial analysis runs for critical Tug load conditions. These runs were made with rigid supports for the baseline four-point (1-1), five-point load balanced (2-1), six-point load balanced (4-1), five-point redundant (2-1R), and six-point redundant (4-1R) configurations. These runs established support reactions and internal body loads due to Tug loading only.

b. Unit support deflection analysis runs were made. Unit twist loading was obtained by releasing the forward Z supports (Station 951) and applying a 1000 pound (4450 N) Z couple load at each support. Unit yaw loading was obtained by releasing the forward Y support (Station 951) and applying a unit 1000 pound (4450 N) Y load at the support. Unit relative twist and yaw deflections are shown in Figure 4.2-71.

Maximum Tug support reactions due to Orbiter deflections were obtained by multiplying the unit Tug deflection data by the maximum Orbiter deflections in Table 4.2-37. These maximum support reactions are summarized in Tables 4.2-38, 4.2-39, and 4.2-40. Tug support point locations are shown in Figure 4.2-72.

Maximum total Tug support loads for the redundant support concepts are listed in Tables 4.2-41 and 4.2-42. The total loads include components due to Tug inertia and

Table 4.2-34. Tug Redundant Support Analysis Model Stiffnesses

Element	AE x		KAG y		KAG z		JG x		EI y		EI z	
	10^7 lb	(10^7 N)	10^7 lb	(10^7 N)	10^7 lb	(10^7 N)	10^{10} lb/ in^2	(10^{10} N/ cm^2)	10^{10} lb/ in^2	(10^{10} N/ cm^2)	10^{10} lb/ in^2	(10^{10} N/ cm^2)
101	7.36	(32.75)	3.72	(16.55)	3.72	(16.55)	35.37	(24.40)	75.36	(52.00)	75.36	(52.00)
201	7.36	(32.75)	3.72	(16.55)	3.72	(16.55)	35.37	(24.40)	75.36	(52.00)	75.36	(52.00)
301	7.36	(32.75)	3.72	(16.55)	3.72	(16.55)	35.37	(24.40)	75.36	(52.00)	75.36	(52.00)
401	7.36	(32.75)	3.72	(16.55)	3.72	(16.55)	35.37	(24.40)	75.36	(52.00)	75.36	(52.00)
501	5.60	(24.92)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	92.48	(63.81)
502	10.50	(46.73)	4.00	(17.80)	4.00	(17.80)	40.00	(27.60)	9.66	(6.67)	9.66	(6.67)
503	10.50	(46.73)	4.00	(17.80)	4.00	(17.80)	40.00	(27.60)	9.66	(6.67)	9.66	(6.67)
504	10.50	(46.73)	16.00	(71.20)	16.00	(71.20)	40.00	(27.60)	9.24	(6.38)	9.24	(6.38)
601	5.60	(24.92)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	87.86	(60.62)
701	5.60	(24.92)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	82.31	(56.79)
801	5.60	(24.92)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	75.84	(52.33)
901	5.76	(25.63)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	69.36	(47.86)
1001	5.76	(25.63)	4.58	(20.38)	7.32	(32.57)	35.37	(24.40)	147.84	(102.01)	64.74	(44.67)
1101	5.76	(25.63)	3.05	(13.57)	9.76	(43.43)	44.52	(30.50)	147.84	(102.01)	76.46	(52.76)
1201	5.76	(25.63)	3.05	(13.57)	9.76	(43.43)	44.52	(30.50)	197.28	(136.12)	71.52	(49.35)
1401	10.40	(46.28)	3.05	(13.57)	9.76	(43.43)	44.52	(30.50)	197.28	(136.12)	65.36	(45.10)
1501	10.40	(46.28)	3.05	(13.57)	9.76	(43.43)	44.52	(30.50)	197.28	(136.12)	57.96	(39.99)
1601	10.40	(46.28)	3.05	(13.57)	9.76	(43.43)	44.52	(30.50)	197.28	(136.12)	51.79	(35.74)
1702	10.50	(46.73)	8.52	(37.91)	8.52	(37.91)	40.00	(27.60)	18.90	(13.04)	32.55	(22.46)
1703	10.50	(46.73)	8.52	(37.91)	8.52	(37.91)	40.00	(27.60)	18.90	(13.04)	32.55	(22.46)
1704	10.50	(46.73)	16.00	(71.20)	16.00	(71.20)	40.00	(27.60)	9.24	(6.38)	9.24	(6.38)

Note: See Figure 4.2-69 for element locations.

Table 4.2-35. Tug Redundant Support Analysis Model Mass Properties

Item	Deploy Ascent Phase			Deploy Retrieve Phase			Retrieve Ascent Phase		
	Weight		cg	Weight		cg	Weight		cg
	lb	(kg)	sta	lb	(kg)	sta	lb	(kg)	sta
Payload	11000	(4990)	791	11000	(4990)	791	0		0
Tug Structure	3964	(1798)	1071	3964	(1798)	1071	3964	(1798)	1071
Deploy Adapter	708	(321)	1201	708	(321)	1201	708	(321)	1201
LH_2 Tank	7820	(3547)	1037	425	(193)	1029	8488	(3850)	1032
LO_2 Tank	40316	(18287)	1180	1131	(513)	1215	44330	(20108)	1176
Total	63808	(28943)	1089	17228	(7815)	906	57490	(26077)	1148

Table 4.2-36. Redundant Support Analysis Load Factors

Condition	Nx (g's) (+ Aft)	Ny (g's) (+ Right)	Nz (g's) (+ Up)
Liftoff	-1.6 ±1.3	±0.7	-0.1 ±1.0
High-Q Boost	-1.8 ±0.2	±0.5	±0.6
Boost Max Load Factor	-3.0 ±0.15	±0.2	-0.3
Orbiter Max Load Factor	-3.0 ±0.15	±0.2	-0.75
Entry			
+ Pitch Maneuver	1.1	0	2.5
- Pitch Maneuver	0.6	0	-1.0
Yaw Maneuver	1.0	±1.25	1.0
Roll Maneuver	0.9	±0.2	1.5
Landing	-0.2 ±1.3	±0.7	2.0 ±1.3

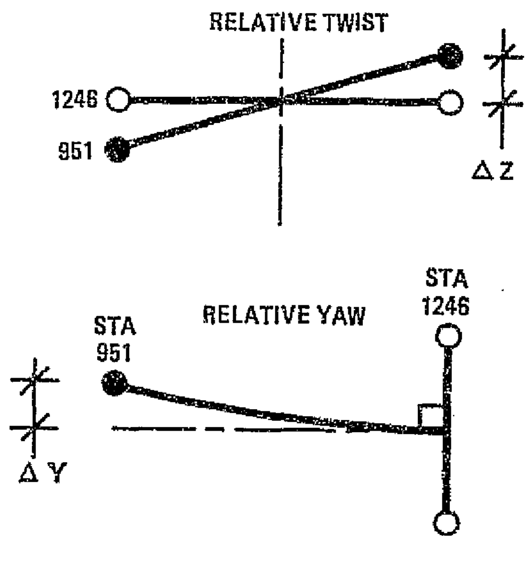


Figure 4.2-70. Definition of Relative Twist and Relative Yaw

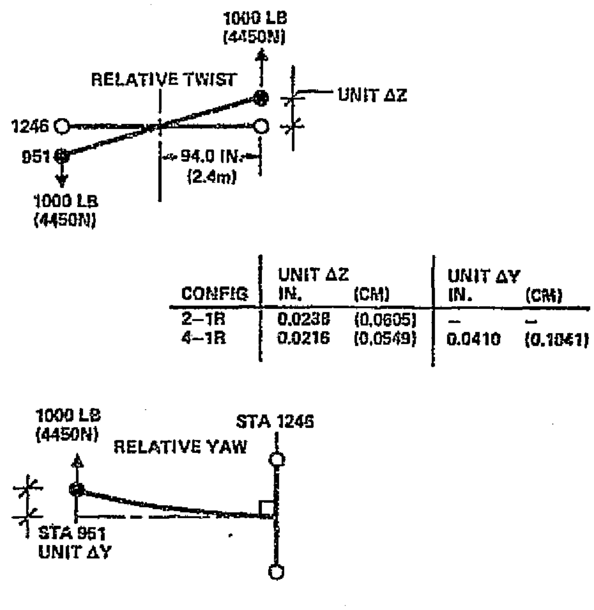


Figure 4.2-71. Tug Unit Twist and Yaw Deflections

Table 4.2-37. Maximum Orbiter Deflections

Condition	ΔZ sill in.	ΔZ sill (cm)	ΔY centerline in.	ΔY centerline (cm)
Liftoff	0.116	(0.295)	0.048	(0.122)
High-Q Boost	0.200	(0.508)	0.146	(0.371)
Max G	0	(0)	0	(0)
Entry Yaw	0.085	(0.216)	0.110	(0.279)
Entry Roll	0.057	(0.145)	0.022	(0.056)
Landing	0.073	(0.185)	0.043	(0.109)

Orbiter deflections. The Tug inertia loads include a correction, based on data from the five- and six-point load balanced support reaction analysis update (Section 4.2.3.8), for the angular accelerations included in the MSFC PF-02-75-31 load factors. Support loads due to Orbiter deflections were combined with the Tug inertia loads in the most conservative manner.

Comparison of the redundant support analysis results with the support reactions calculated for load balanced support concepts (Table 4.2-43) indicates that this approach is not only feasible, but preferable, with respect to exceeding Orbiter support point loading capability.

This comparison of support reactions between the five- and six-point redundant and load-balanced systems indicates only minor increases due to redundancy and, in the six-point system a small decrease in the $\pm Z_1$, Z_2 reactions. Redundancy does not result in any increase in reaction exceedance since those reactions responsible for exceedance in the five-point load-banced system ($\pm X_1$, X_2) are unaffected by redundancy and all other reactions which do increase are still well within Orbiter capability.

In addition to support reactions, Tug body loads and deflections were compared for the redundant and statically determinant support concepts.

The three body-load charts in Figure 4.2-73 present comparisons of maximum absolute value envelopes of total load on the vehicle cross-section versus station for the candidate support systems. A comparison of transverse shear indicates no major advantage among the various support systems.

Table 4.2-38. Configuration 2-1R Redundant Support Loads — Orbiter Twist Deflection (θ_x)

Load Condition	X_1		X_2		Y_1		Y_2		Z_1		Z_2		Z_3		Z_4	
	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)
Unit 1000 lb (Z3/Z4)	0		0		0		0		-1000	(-4450)	1000	(4450)	1000	(4450)	-1000	(-4450)
Liftoff	0		0		0		0		-4882	(-21725)	4882	(21725)	4882	(21725)	-4882	(-21725)
High-Q Boost	0		0		0		0		-8427	(-37500)	8427	(37500)	8427	(37500)	-8427	(-37500)
Maximum G	0		0		0		0		0	(0)	0	(0)	0	(0)	0	(0)
Entry Yaw	0		0		0		0		-3574	(-15904)	3574	(15904)	3574	(15904)	-3574	(-15904)
Entry Roll	0		0		0		0		-2405	(-10702)	2405	(10702)	2405	(10702)	-2405	(-10702)
Landing	0		0		0		0		-3070	(-13662	3070	(13662)	3070	(13662)	-3070	(-13662)

Table 4.2-39. Configuration 4-1R Redundant Support Loads — Orbiter Yaw Deflection (Y)

Load Condition	X_1		X_2		Y_1		Y_2		Z_1		Z_2		Z_3		Z_4	
	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)
Unit 1000 lb (Y2)	-1595	(-7053)	1586	(7053)	-1000	(-4450)	1000	(4450)	273	(1214)	-273	(1214)	-291	(-1295)	291	(1295)
Liftoff	-1875	(-8344)	1875	(8344)	-1183	(-5264)	1183	(5264)	322	(1433)	-322	(1433)	-344	(-1530)	344	(1530)
High-Q Boost	-5625	(-25031)	5025	(25031)	-3549	(-15793)	3549	(15793)	967	(4303)	-967	(4303)	-1031	(-4588)	1031	(4588)
Max G	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
Entry Yaw	-4260	(-18[illegible]7)	4260	(18957)	-2686	(-11962)	2688	(1[illegible]362)	733	(3262)	-733	(3262)	-781	(-3475)	781	(3475)
Entry Roll	-854	(-3800)	854	(3800)	-539	(-2399)	539	(2399)	147	(654)	-147	(654)	-157	(-698)	157	(699)
Landing	-1655	(-7365)	1655	(7365)	-1044	(-4650)	1044	(4650)	285	(1268)	-285	(1268)	-303	(-1348)	303	(1348)

Table 4.2-40. Configuration 4-1R Redundant Support Loads — Orbiter Twist Deflection (θ_x)

Load Condition	X_1		X_2		Y_1		Y_2		Z_1		Z_2		Z_3		Z_4	
	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)	lb	(N)
Unit 1000 lb (Z3/Z4)	487	(2167)	-487	(-2167)	307	(1366)	-307	(-1366)	-994	(-4423)	994	(-4423)	1000	(4450)	-1000	(-4450)
Liftoff	2609	(11610)	-2609	(-11610)	1646	(7325)	-1646	(-7325)	-5332	(-23727)	5332	(-23727)	5362	(23861)	-5362	(-23861)
High Q Boost	4504	(20043)	-4504	(-20043)	2842	(12647)	-2842	(-12647)	-9204	(-40958)	9204	(-40958)	9256	(41189)	-9256	(-41189)
Maximum G	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
Entry Yaw	1910	(8500)	-1910	(-8500)	1205	(5362)	-1205	(-5362)	-3904	(-17373)	3904	(-17373)	3926	(17631)	-3926	(-17631)
Entry Roll	1286	(5723)	-1286	(-5723)	811	(3609)	-811	(-3609)	-2627	(-11690)	2627	(-11690)	2642	(11757)	-2642	(-11757)
Landing	1641	(7302)	-1641	(-7302)	1035	(4606)	-1035	(-4606)	-3353	(-14921)	3353	(-14921)	3372	(15005)	-3372	(-15005)

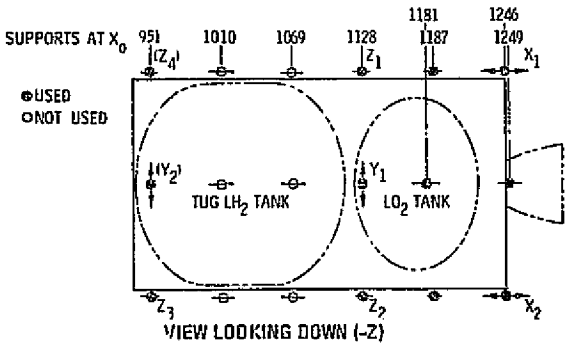


Figure 4.2-72. Tug Support Point Locations

However, the six-point support systems exhibit substantially lower bending moments over virtually the entire vehicle length — indicating a potential weight saving in sidewall reinforcement and a consequent performance advantage over the four and five-point systems.

Even more dramatic is the comparison of torsional moment ranging from zero in the five-point load-balanced system to somewhat above six-million in-lb in the four-point system. In this comparison the first distinction is found between load-balanced and redundant systems with identical supports. The six-point redundant system is substantially better than the corresponding load-balanced system and further provides an additional potential weight saving over all systems except the five-point load-balanced system.

The comparison of Tug lateral (Y) deflection at the forward Z support plane (X_0 951) in Table 4.2-44 illustrates yet another advantage for the six-point redundant system.

On the basis of Tug support reaction exceedance, Tug internal body loads, and Tug deflections, the redundant support concepts are not only feasible but are desirable. In particular, the six-point redundant support concept provides the minimum body loads and deflections while eliminating any support reaction exceedance.

Redundant Support Implementation. The preceding analysis has shown not only that redundant support systems are feasible but that a six-point dual-redundant system is desirable in view of acceptable reactions and reduced Tug body loads and deflections.

Implementation of a redundant system involves a consideration of possible misalignment at redundant support locations. The geometric situation is illustrated in Figure 4.2-74. These potential ΔZ and ΔY gaps at the redundant supports are due to assembly tolerances on the Orbiter and Tug, residual stresses in the Tug and Orbiter structure, and inertia and thermal loads in the structure. To implement a redundant support system, the Tug systems must provide a capability to eliminate these gaps at the supports.

For the fourth Z (redundant) support concept, elimination of the ΔZ gap may be accomplished by:

a. Providing special Orbiter Z fittings with adjustment capability.

b. Forcing the gap closed by the use of special AGE, Orbiter Z latches, the RMS, the Tug forward umbilical panel or the Tug deployment pivot actuator.

Table 4.2-41. Configuration 2-1R Maximum Support Point Loads

Support	Critical Condition	Tug Loads (lb)	Ang Accel Loads (lb)	Orbiter Twist Loads (lb)	Orbiter Yaw Loads (lb)	Total Loads lb	(N)
Maximum Support Loads (+)							
X_1	Entry Yaw	48973	4827	0	0	53800	(239410)
X_2	Entry Yaw	48973	4827	0	0	53800	(239410)
Y_1	Liftoff	44664	514	0	0	45178	(201042)
Y_2	-	0	0	0	0	0	(0)
Z_1	Liftoff	32184	528	4882	0	37594	(167293)
Z_2	Liftoff	32184	-528	4882	0	36538	(162594)
Z_3	Landing	34567	1529	3070	0	39166	(174289)
Z_4	Landing	32050	1529	3070	0	36649	(163088)
Minimum Support Loads (-)							
X_1	Liftoff	-130570	-2570	0	0	-133140	(-592473)
X_2	Liftoff	-105060	180	0	0	-104880	(-466716)
Y_1	Liftoff	-44664	-514	0	0	-45178	(-201042)
Y_2	-	0	0	0	0	0	0
Z_1	Liftoff	-40380	-528	-4882	0	-45790	(-203765)
Z_2	High-Q Boost	-24131	-657	-8427	0	-33216	(-147811)
Z_3	Liftoff	-22980	-816	-4882	0	-28678	(-127617)
Z_4	Liftoff	-13504	-816	-4882	0	-19202	(-85449)

Note: Loads shown are as applied to Tug by Orbiter using standard sign convention: +X aft, +Y right, +Z up.

Table 4.2-42. Configuration 4-1R Maximum Support Point Load

Support	Critical Condition	Tug Loads (lb)	Ang Accel Loads (lb)	Orbiter Twist Loads (lb)	Orbiter Yaw Loads (lb)	Total Loads lb	(N)
Maximum Support Loads (+)							
X_1	Entry Yaw	14818	0	1910	4260	20988	(93396)
X_2	Entry Yaw	14818	0	1910	4260	20988	(93396)
Y_1	Liftoff	26625	524	1646	1183	29978	(133402)
Y_2	Entry Yaw	20822	3044	1205	2688	27759	(123528)
Z_1	Liftoff	28472	536	5332	322	34662	(154246)
Z_2	Liftoff	28472	-536	5332	322	33590	(149476)
Z_3	Landing	37956	1528	3372	303	43159	(192058)
Z_4	Landing	37956	1528	3372	303	43159	(192058)
Minimum Support Loads (-)							
X_1	Maximum G	-101420	0	0	0	-101420	(-451319)
X_2	Maximum G	-99570	0	0	0	-99570	(-443086)
Y_1	Liftoff	-26625	-524	-1646	-1183	-29978	(-133402)
Y_2	Liftoff	-21963	-1621	-1646	-1183	-26413	(-117538)
Z_1	Liftoff	-36668	-528	-5332	-322	-42850	(-190682)
Z_2	High-Q Boost	-19856	-657	-9204	-967	-30684	(-136544)
Z_3	Liftoff	-29363	-826	-5362	-344	-35895	(-159733)
Z_4	High-Q Boost	-15114	-816	-9256	-1031	-26217	(-116666)

Table 4.2-43. Support Reaction Comparison (Loads Applied to Orbiter)

Support Configuration	Reactions 10^3 lb (10^3 N)								Cumulative Exceedance 10^3 lb (10^3 N)
	X_1, X_2		Y_1	Y_2	Z_1, Z_2		Z_3, Z_4		
	(+)	(-)	(+/-)	(+/-)	(+)	(-)	(+)	(-)	
Five-Point									
Balanced (2-1)	133.1 (592.3)	53.8 (239.4)	45.2 (201.1)	-	45.2 (201.1)	37.0 (164.6)	19.1 (85.0)	35.5 (158.0)	89.8 (399.6)
Redundant (2-1R)	133.1 (592.3)	53.8 (239.4)	45.2 (201.1)	-	45.8 (203.8)	36.5 (162.4)	28.7 (127.7)	39.2 (174.4)	89.8 (399.5)
Six-Point									
Balanced (4-1)	100.5 (447.2)	9.9 (44.1)	35.1 (156.2)	29.4 (130.8)	43.9 (195.4)	37.7 (167.8)	19.1 (85.0)	35.5 (158.0)	0 (0)
Redundant (4-1R)	101.4 (451.2)	21.0 (93.4)	30.0 (133.5)	27.6 (122.8)	42.9 (190.9)	33.6 (149.5)	35.9 (159.8)	43.2 (192.2)	0 (0)
Orbiter Capability	110.0	32.0	56.0	70.0	50.0	50.0	67.0	52.0	

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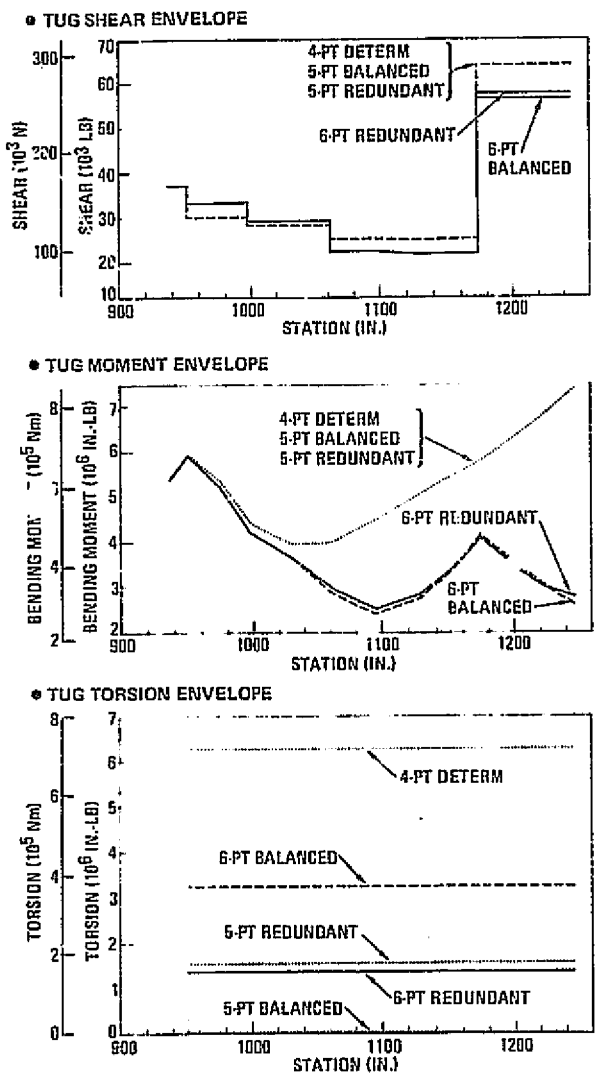

Figure 4.2-73. Tug Body Loads Comparison

For the second Y (redundant) support concept, elimination of the ΔY gap may be accomplished by:

a. Providing a special Orbiter Y fitting receptacle with adjustment capability

b. Forcing the gap closed by the use of special AGE, Orbiter Z latches, the RMS, the Tug forward umbilical panel, a mechanized forward Y keel fitting (either ±Y or ±Z force), or the Tug deployment pivot actuator.

Due to the many options involved, the complex evaluation required, and the unknown Tug and Orbiter tolerance and misalignment requirements, a detailed analysis of the redundant support implementation was beyond the scope of this preliminary study. However, Table 4.2-45 provides a preliminary assessment of the methods identified for overcoming misalignment and indicates those that should be studied further. This preliminary assessment indicates that implementation of both the redundant Z and redundant Y support concepts are feasible. Further study is needed to identify the best option for implementation.

Table 4.2-44. Tug Lateral (Y) Deflection Comparison at X_0 951

Configuration	Deflection in.	Deflection (cm)
Four-Point Baseline	1.25	(3.18)
Five-Point Balanced	0.95	(2.41)
Five-Point Redundant	0.93	(2.36)
Six-Point Balanced	0.38	(0.97)
Six-Point Redundant	0.17	(0.43)

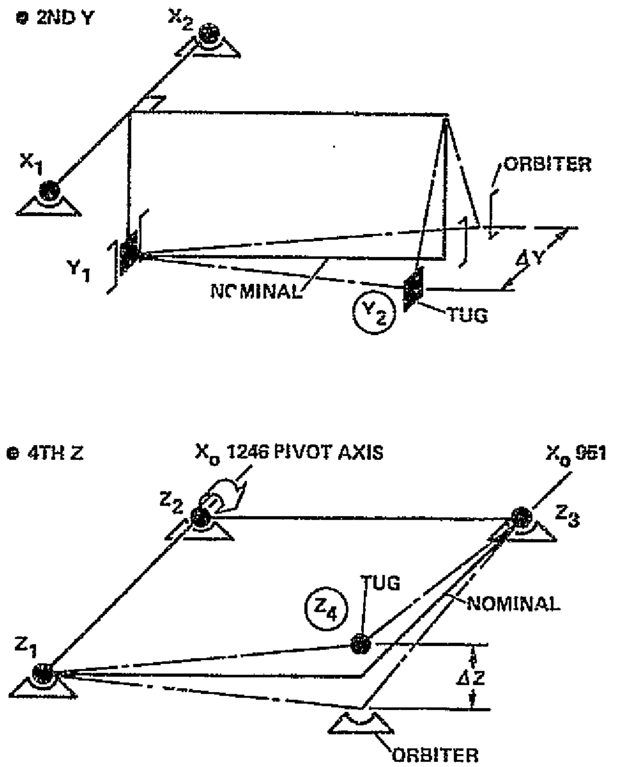

Figure 4.2-74. Redundant Support Implementation

Conclusions. This analysis has demonstrated that single- or dual-redundant Tug-support concepts are feasible both from the aspect or point of view of loads induced by Orbiter deflections and tolerance and misalignment considerations for support implementation. The dual-redundant (Y and Z) support system is not only feasible but is desirable in view of acceptable reactions and reduced Tug body loads deflections. Further detailed analysis should be performed for the six-point dual-redundant support concept, especially in the areas of tolerance and misalignment requirements and implementation of the redundant supports.

4.2.3.10 Weight/Performance Evaluation Update. During the preliminary screening analysis, weight and performance evaluations were conducted for each of 21 candidate support arrangements (Section 4.2.2.3). At that time only preliminary weight data was available since body and frame load distributions were based on conventional engineering theory modified using previous Convair STSS data to account for estimated peaking near support reactions and for shell support effects on frame loads. Since that time detailed finite element analyses have been conducted, yielding more realistic load distribution and deflection data (Sections 4.2.3.1 and 4.2.3.9). This data forms the basis for the latest weight/performance update.

Figure 4.2-75 illustrates the method employed in this task. It is essentially identical to the method previously shown in Figure 4.2-21 except for incorporating the latest finite element data. Those items that vary in weight between candidate support systems are tabulated at left. They are divided into "Tug body" and "Non-Tug" categories since a different performance partial applies to each.

The inital Tug + adapter body configuration for this task is assumed to be a uniform composite sandwich sidewall with minimum gage facings, and no Orbiter interface frames, support fittings or latch longerons. The Δ-weights tabulated for each candidate support system then represent the unique additional material required by that specific system to withstand its own unique load distributions.

Table 4.2-45. Tug Redundant Support Option Assessments

Redundant Support	Option to Close Gap	Effectivity: Pad	Effectivity: Orbit Out	Effectivity: Orbit In*	Comment			Study Further:
Second Y	• Adjust receptacle	X	O	O	Removes majority of assy tolerance			X
	• Force, using:				Position	Force		
	AGE	X	O	O	Good	High		X
	Orbiter Z-latches	?	O	?	Good	High	±Z Stroke?	X
	RMS	O	O	O	Fair	Very low		
	Fwd Umbil Panel	?	?	?	Fair	Low	±Z Stroke?	
	Mechanize Keel:							
	• ±Y (Open/Shut)	X	X	X	Very good	As reqd		X
	• ±Z (Push/Pull)	X	X	X	Very good	As reqd	Ramp, Friction	?
	Pivot Actuator	O	X	X	Fair	High	Concurrent Loads	?
Fourth Z	• Adjust Z-Fitting	X	N/A	O	Removes majority of assy tolerance			X
	• Force, using:				Position	Force		
	AGE	X	N/A	O	Good	High	±Z adjust reqd	X
	Orbiter Latch	X	N/A	X	Very good	High		X
	RMS	O	N/A	O	Fair	Very low		
	Fwd Umbil Pnl	O	N/A	O	Fair	Low		
	Pivot Actuator	O	N/A	O	Very poor	High		

*Not mandatory if Orbiter X-capability increased: ascend with 6-pt support, descend with 5-point support.

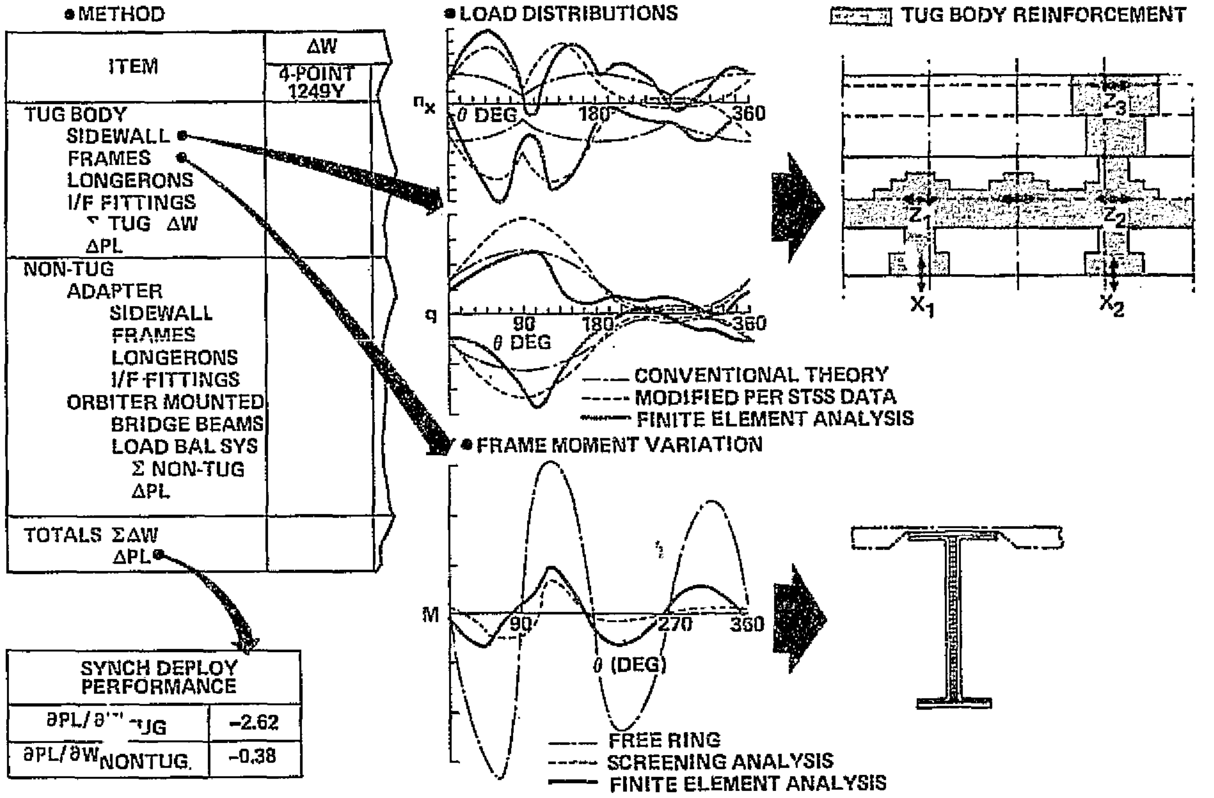

Figure 4.2-75. Weight/Performance Update Method

Internal body loads data (developed in Section 4.2.3.1) similar to that illustrated was mapped onto sidewall flat patterns to identify contours of approximately constant load. Necessary facing thickness increases were then determined for those regions where the minimum gage facings were insufficient to withstand the internal loads. Boundaries of regions of constant facing thickness were smoothed to reflect probable manufacturing ply module steps. Total ply count in each step was chosen to provide the required strength and to maintain symmetry of facings about the sandwich centerline.

Frame weights were determined from parametric weight versus moment data based on representative composite designs. Load data similar to that shown was squared-off into circumferential increments of constant load and each increment weighed from the parametric data for its proportion of the total circumference. Weights of shear reinforcement and local load introduction provisions at support fittings were also included.

Support fitting weights were taken from Section 4.2.3.3, Table 4.2-21.

Latch longeron quantity and weights were based on the distribution of element loads in the finite element analysis output.

Bridge beam and load-balancing system unit weights were the same as used previously in Section 4.2.2.3 except that in support arrangement 6-1R an additional 10 lb (4.5 kg) allowance was included in the forward Y keel fitting for a mechanism to overcome the potential misalignment discussed in Section . 2.3.9 (see Figure 4.2-74 and Table Table 4.2-45).

Sidewall Reinforcement. The revised Tug sidewall reinforcement analysis used the results of the Tug finite element analysis (Section 4.2.3.1) to generate internal Tug body loads. The basic analysis procedure was similar to that used in the preliminary weight/performance evaluation (Section 4.2.2.3) except that only the five selected configurations (1-1, four-point; 2-1, five-point load-balanced; 2-1R, five-point redundant; 4-1, six-point load-balanced; 4-1R, six-point redundant) were evaluated. Since, for configurations 1-1 and 2-1, body load plots were directly available from the finite element analysis (see Section 4.2.3.1) a detailed weights analysis was performed for each of these configurations. Using the finite element analysis loads and the graphite/epoxy composite sandwich allowables shown in Figure 4-2-76, flat pattern maps of required Tug body sidewall reinforcement were generated. These body reinforcement requirements are shown in Figure 4.2-77 for configuration 1-1 and in Figure 4.2-78 for configuration 2-1.

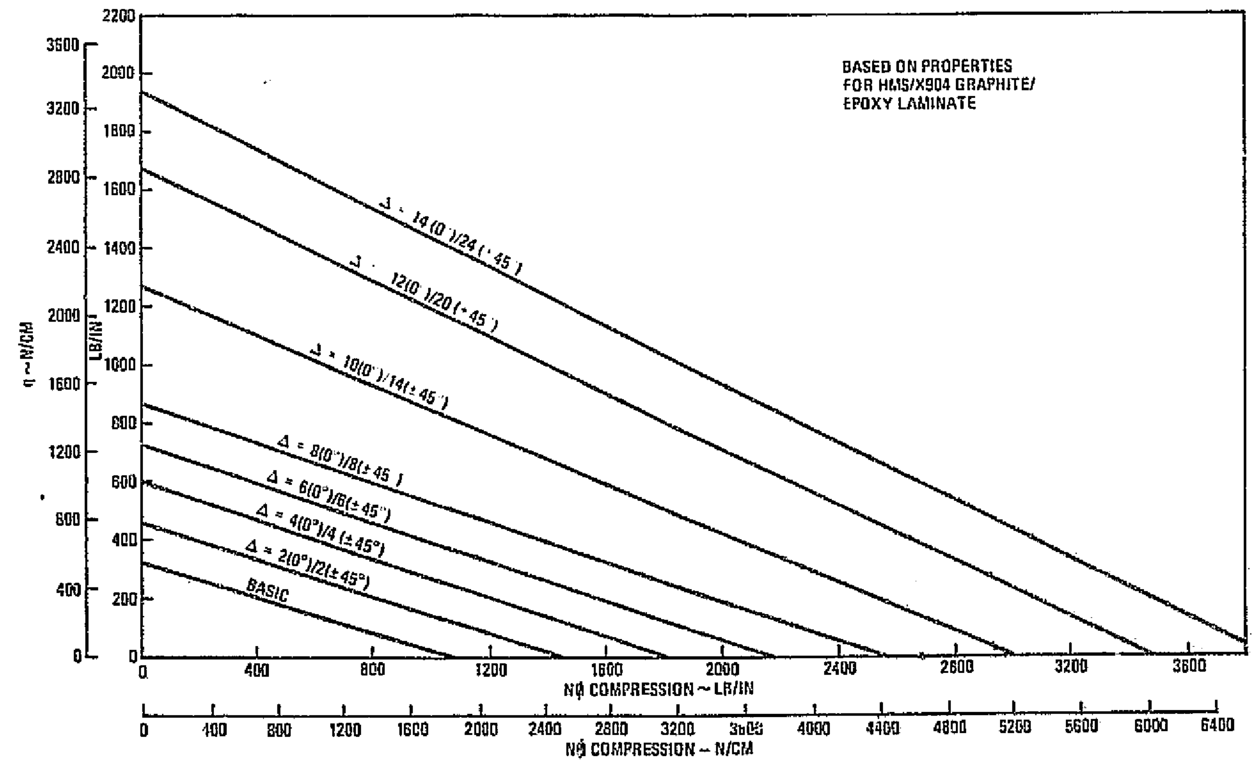

Figure 4.2-76. Graphite/Epoxy Tug Shell Allowable Loading (Limit)

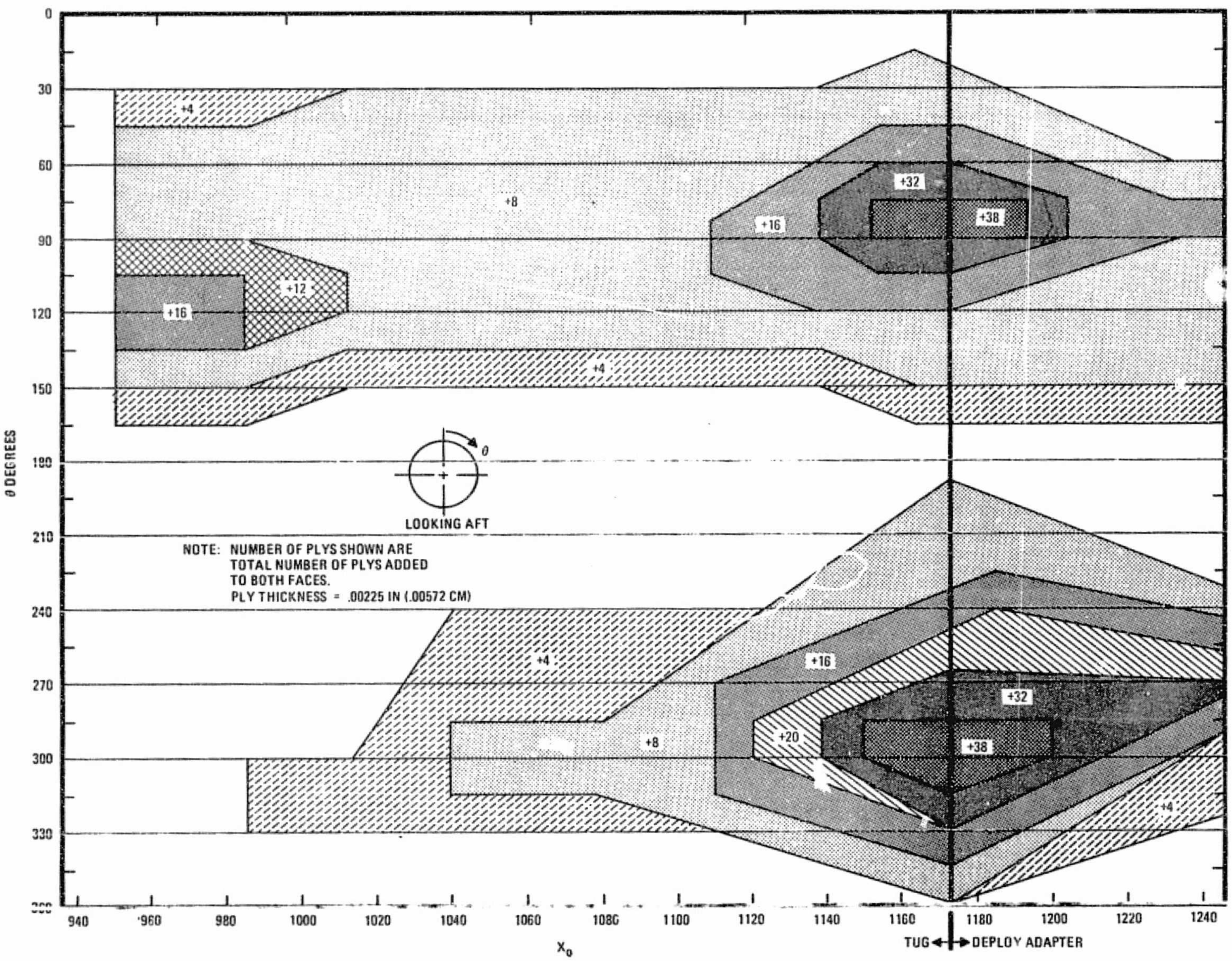

Figure 4.2-77. Tug Body Sidewall Reinforcement, Configuration 1-1

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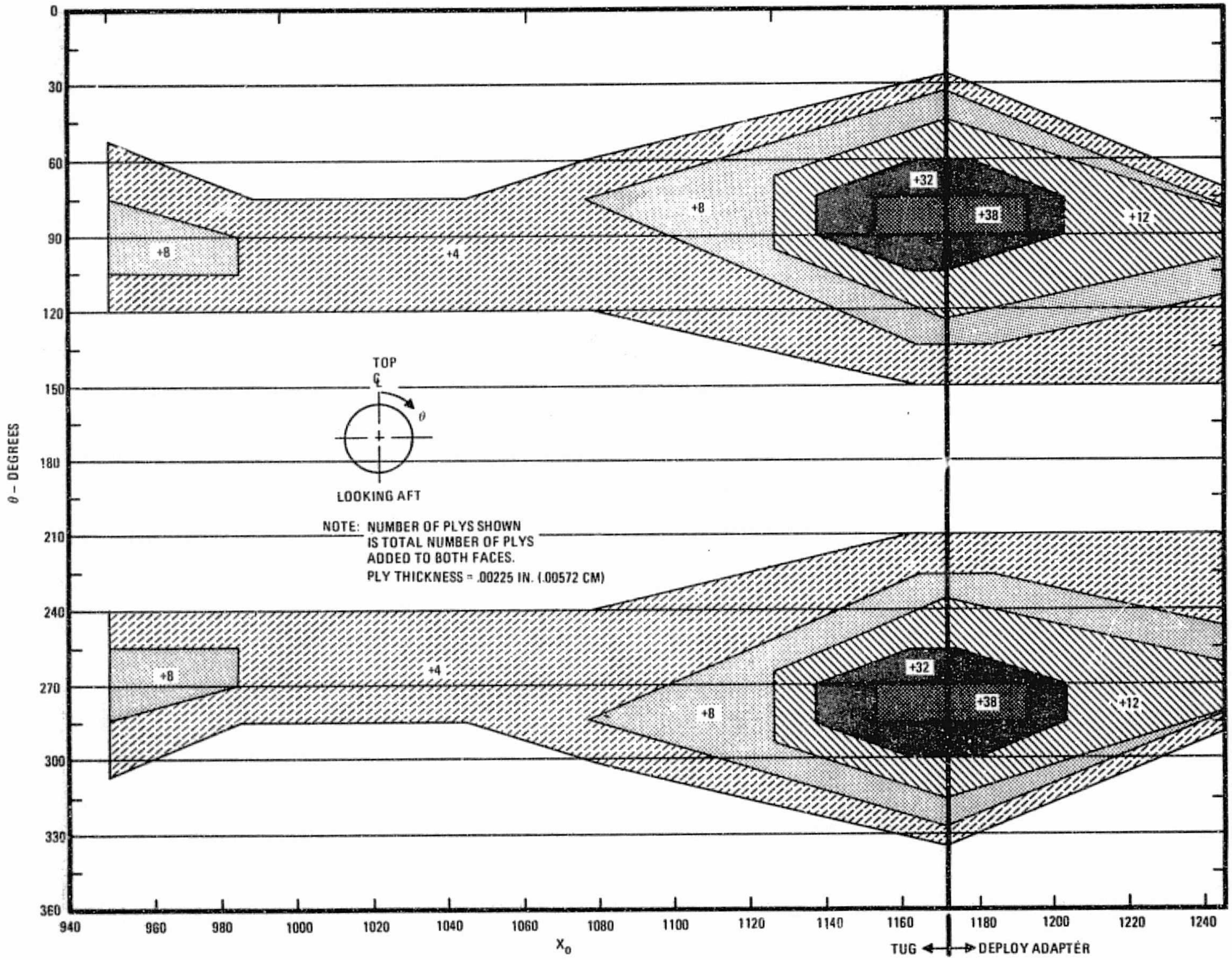


Figure 4.2-78. Tug Body Sidewall Reinforcement, Configuration 2-1

Using these body reinforcing plots, reinforcement weights were calculated using a constant depth sandwich and face sheet density of 0.58 lb/in^3 (16.1 g/cm^3). The Tug design load factors used in the finite element analysis were the original MSFC 68M00039-1 values supplied at the start of the program. Since the final revised set of Tug design load factors (MSFC PF02-75-31) were supplied late in the study, they could not be incorporated in the finite element analysis. Therefore, to reflect these latest loads, a correction was applied to the calculated Tug sidewall reinforcement.

Evaluating the effects of load factor and support reaction changes on body loads, the calculated weights were multipled by a reduction factor of 0.79. Corrected weights for configurations 1-1 and 2-1 are shown in Table 4.2-46.

Table 4.2-46. Tug Sidewall Reinforcing Weight Correction

Configuration	Δ Wt (MSFC 68M00039-1)		Corrected Δ Wt (MSFC PF02-75-31)	
	Tug lb (kg)	Deploy Adapt lb (kg)	Tug lb (kg)	Deploy Adapt lb (kg)
1-1 (Four-Point)	85.9 (39.0)	46.1 (20.9)	67.8 (30.8)	36.4 (16.5)
2-1 (Five-Point)	46.3 (21.0)	31.6 (14.3)	36.6 (16.6)	25.0 (11.3)

To calculate sidewall reinforcing weight for the alternate support configurations the corrected Δ weights for configurations 1-1 and 2-1 in Table 4.2-46 were adjusted for the changes in support reactions and overall axial, shear, and bending load distributions in the Tug body and deploy adapter.

An alternate support configuration included in the evaluation was a modified four-point support system with the Y fitting moved forward from X_o 1249 to X_o 1128.

Tug sidewall reinforcing weights are summarized in Table 4.2-47.

These body reinforcing weights are Δ weights above the basic graphite/epoxy composite sandwich assumed for the Tug structural shell and reflect the latest MSFC PF02-75-31 loads.

Frames. In the screening analysis weight/performance evaluation, frames were sized based on bending moment distribution only. These were derived using existing Convair STSS data to modify conventional shell-supported frame moment distributions. In the subsequent finite element analysis, data was generated giving frame axial and

Table 4.2-47. Tug Sidewall Reinforcing Weight

Configuration	Δ Weight Tug lb (kg)		Δ Weight Deploy Adapter lb (kg)	
1-1 (Four-Point Baseline)	67.8	(30.8)	36.4	(16.5)
1-1 (Four-Point-1128Y)	64.8	(29.4)	28.8	(13.1)
2-1 (Five-Point Balanced)	36.6	(36.6)	25.0	(11.3)
2-1R (Five-Point Redundant)	39.3	(17.8)	27.0	(12.2)
4-1 (Six-Point Balanced)	31.4	(14.2)	20.9	(9.5)
4-1R (Six-Point Redundant)	33.7	(15.3)	21.9	(9.9)

transverse shear force distributions in addition to more representative moment distributions. Figures 4.2-35B and C in Section 4.2.3.1 showed typical frame loads distributions at two major frame locations computed using accelerations per MSFC 68M00039-1. In addition, Figure 4.2-79 compares the moment distribution in the X_O 951 frame based on the finite element analysis with the preliminary screening data.

This update was based on the application of the later finite element data (modified to account for the change in reference accelerations from MSFC 68M00039-1 to MSFC PF02-75-31) to the major interface frames (at X_O 951, 1128, 1182, 1246) in the remaining candidate support arrangements. (See Section 4.2.3.8, Figure 4.2-64 and Section 4.2.3.9, Figure 4.2-68 for candidate arrangements.) The original major frame concept, materials, and allowables (Section 4.2.2.3, Figure 4.2-29) were retained but the radial load introduction fittings at Z support locations were deleted as a result of the support fitting design update (Section 4.2.3.3). New basic frame weight data was developed parametrically (as a function of frame depth) from the previous data (Section 4.2.2.3, Figure 4.2-30) to reflect frame cap sizing based on the combined effects of bending moment and axial force. The weight of web reinforcement (in addition to the basic sandwich facings) required to withstand the full range of transverse shear forces

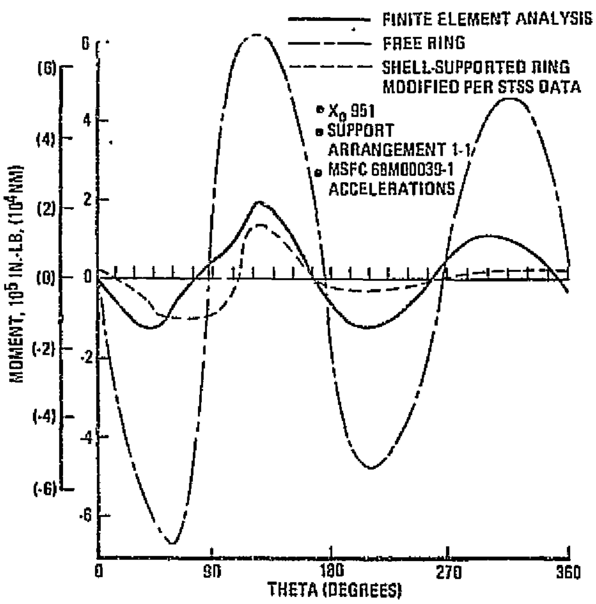


Figure 4.2-79. Frame Moments: Comparison of Finite Element Data with Preliminary Screening Data

was also developed parametrically with frame depth. Figure 4.2-80 presents the basic frame and shear reinforcement weights and the computational basis for each.

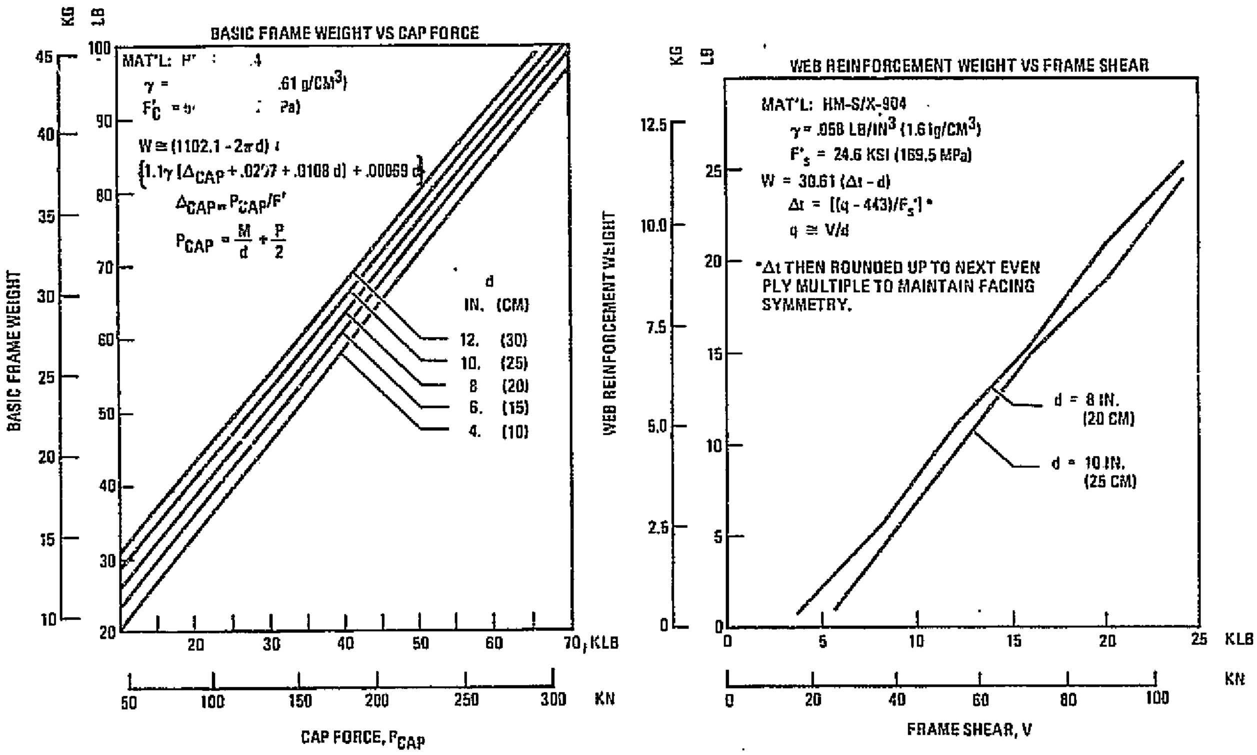


Figure 4.2-80. Basic Frame and Web Reinforcement Weights versus Frame Loads

Frame weights for each location in each support arrangement were computed using the following methodology:

a. The appropriate moment and axial force distributions were each "squared-off" into a series of regions of constant M and P, and the corresponding cap force (P_{CAP}) was computed for each M, P pair.

b. The weight of each region, of width θ, was computed based on $\theta/360$ times the total basic frame weight from Figure 4.2-80 for the appropriate P_{CAP}.

c. As before, a Δ-weight due to 2 in. (5 cm) frame depth increase was added to those frames expected to be stiffness critical (Section 4.2.3.3).

d. As above, the shear force distributions were also "squared-off" into a series of regions of constant V, and the weight of each region was computed based on $\theta/360$ times the total web reinforcement weight from Figure 4.2-80 for the appropriate shear force, V.

e. The weight of the local load introduction provisions at Y-support locations was taken from the previous parametric data (Section 4.2.3.3, Figure 4.2-31).

f. The sum of the weights from items b through e was increased by 10 percent for contingency.

As in the screening evaluation (Section 4.2.2.3), the final choice of frame depth was based in part on weight optimization and in part on cap proportions. A depth of 8.0 in. (20.3 cm) was chosen at all locations with the following exceptions:

1. The frame at X_o 1181 was constrained to a depth of 6.0 in. (15.2 cm) and revised to a J cross section to maintain clearance of the inboard cap from the oxidizer tank support struts.

2. Frames with single supports (X_o 951 in arrangements 1-1, 1-1A; X_o 1128 in arrangement 1-1A) were sized for 8.0 in. (20.3 cm) depth then increasd to 10 in. (25.9 cm) depth with no cap area decrease, to provide additional stiffness.

The resulting updated frame weights are given in Table 4.2-48.

Latch Longerons. In the screening weight/performance evaluation, 16 equally spaced latches were provided at the X_o 1172.9 Tug/adapter separation plane. Latch loads were developed (using STSS-based peaking factors) from which it was found that all latch loads lay within two distinctly different levels of load intensity and, consequently, weights for two longeron configurations were developed. (Section 4.2.2.3).

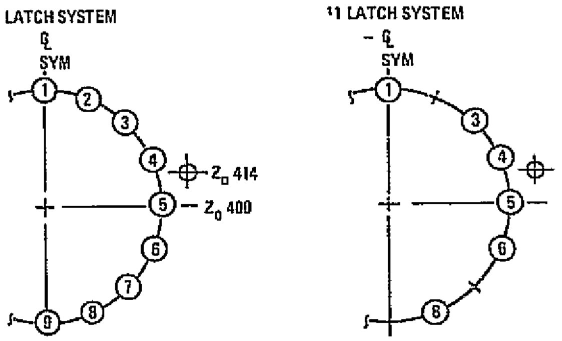
As a result of the finite element analysis (Section 4.2.3.1), it was found that the latches nearest the X-longeron experience no tension for non-crash flight conditions (see locations 3 and 4 in Section 4.2.3.1, Table 4.2-17F) whereas those nearest the top and bottom centerlines (locations 1, 6, and 7) experience maximum tension. The values previously shown in Table 4.2-17F were mainly due to the very severe pitch accelerations in the launch release condition in the original MSFC 68M00039-1 set of accelerations (Section 4.2.1.3, Table 4.2-2). Correcting these values for the less severe peak pitch accelerations in MSFC PF02-75-31 results in a reduction in magnitude of approximately 50 percent. Presumably, then, deletion of all latches except those near the top and bottom centerline would have been permissible. However, this was found unrealistic in view of the requirement that the Tug/adapter structure remain intact in the crash condition during which the separation plane (X_o 1172.9) is subjected to maximum tension loads that are highly concentrated near the X-longerons on the sides of the vehicle. Consequently, latches were also required near the X-longerons to transmit longitudinal crash reactions.

Initially it was assumed that a full complement of 16 latches would again be required. However, a comparison of the maximum latch tension forces in the 16-latch set with

Table 4.2-48. Updated Frame Weights

Frame Location/ Support Arrangement	Weights						
	Basic Frame	Δ for Stiffness	Δ for Shear	Δ at Y Support	Sub-Total	Totals (lb)	Totals (kg)
X_0 951/ 1-1	34.5	2.6	0.4	-	37.5	41.3	18.8
1-1A	34.5	2.6	0.4	-	37.5	41.3	18.8
2-1	30.2	-	-	-	30.2	33.2	15.1
2-1R	33.2	-	-	-	33.2	36.5	16.6
4-1	33.0	-	-	2.9	35.9	39.5	17.9
4-1R	40.2	-	-	2.8	43.0	47.3	21.5
X_0 1128/1-1	9.8	-	-	-	9.8	10.8	4.9
1-1A	22.1	2.6	1.0	3.5	29.2	32.1	14.6
2-1	9.8	-	-	-	9.8	10.8	4.9
2-1R	9.8	-	-	-	9.8	10.8	4.9
4-1	9.8	-	-	-	9.8	10.8	4.9
4-1R	9.8	-	-	-	9.8	10.8	4.9
X_0 1181/1-1	27.5	-	0.5	-	28.0	30.8	14.0
1-1A	24.0	-	0.4	-	29.4	26.8	12.2
2-1	27.5	-	0.5	-	28.0	30.8	14.0
2-1R	27.5	-	0.5	-	28.0	30.8	14.0
4-1	23.0	-	0.3	-	23.3	25.6	11.6
4-1R	23.5	-	0.3	-	23.8	26.2	11.9
X_0 1246/1-1	66.4	-	4.9	3.5	74.8	82.3	37.4
1-1A	45.0	0	2.0	-	47.0	51.7	23.5
2-1	57.1	-	3.8	3.5	64.4	70.8	32.1
2-1R	57.7	-	3.8	3.5	65.0	71.5	32.5
4-1	52.5	-	3.7	3.2	59.3	65.2	29.6
4-1R	48.3	-	3.7	2.9	54.9	60.4	27.4

those conservatively estimated for an 11-latch array resulted in selection of the latter configuration. Figure 4.2-81 compares the two systems and the latch loads in each.



LATCH LOCATION	LATCH TENSION			
	16 LATCH SYS		11 LATCH SYS	
	lb	N	lb	N
1	14727	65535	22090	98301
2	5757	25619		
3	12450	55403	12450	55403
4	18673	83108	18676	83108
5	18676	83108	18676	83108
6	12450	55403	12450	55403
7	4698	20906		
8	14934	66456	21353	95021
9	12839	57134		

Figure 4.2-81. Latch System Comparison

Selection of the 11-latch system resulted in the deletion of five latch mechanisms and their associated longerons on both the Tug and adapter. This was assumed to result in an improvement in latch system reliability as well as a cost benefit due to procurement of fewer (albeit individually heavier) components.

The resulting latch longeron weights are presented in Table 4.2-49 for the six candidate support arrangements.

Summary. The final weight/performance comparison of the six remaining support arrangement candidates is shown in Figure 4.2-82, and the updated detailed summary is presented in Table 4.2-50.

4.2.4 RECOMMENDED STRUCTURAL INTERFACE. This section summarizes the final selection of recommended

Table 4.2-49. Updated Latch Longeron Weights

Support Arrangement	Weights			
	Tug Body		Non-Tug	
	lb	kg	lb	kg
1-1	21.5	9.8	33.1	15.0
1-1A	18.5	8.4	28.2	12.8
2-1	21.5	9.8	33.1	15.0
2-1R	21.5	9.8	33.1	15.0
4-1	13.5	6.1	20.1	9.1
4-1R	14.8	6.7	22.3	10.1

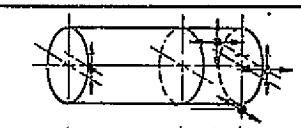
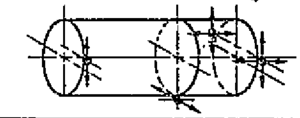
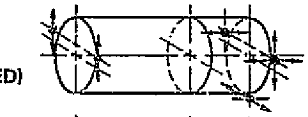
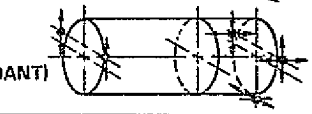
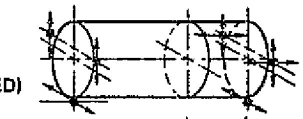
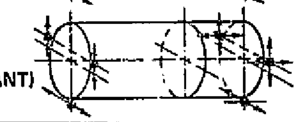
SUPPORT CONFIGURATION		ITEM	COMPARISON ΔWEIGHT LB	ΔWEIGHT kg	ΔPAYLOAD LB	ΔPAYLOAD kg
1-1 (4-POINT 1249 Y)		TUG NON-TUG Σ	174.2 372.1 546.3	79.1 168.9 248.0	-456.4 -141.4 -597.8	-207.2 -64.2 -271.4
1-1A (4-POINT 1128 Y)		TUG NON-TUG Σ	207.2 274.7 481.9	94.1 124.7 218.8	-592.9 -104.4 -647.3	-246.5 -47.4 -293.9
2-1 (5-POINT BALANCED)		TUG NON-TUG Σ	158.7 593.9 752.6	72.0 269.6 341.7	-415.8 -225.7 -641.9	-188.8 -102.5 -291.4
2-1R (5-POINT REDUNDANT)		TUG NON-TUG Σ	165.1 485.3 650.4	75.0 220.3 295.3	-432.6 -184.4 -617.0	-196.4 -83.7 -280.1
4-1 (6-POINT BALANCED)		TUG NON-TUG Σ	169.3 803.5 972.8	76.9 364.8 441.7	-443.6 -305.3 -748.9	-201.4 -138.6 -340.0
4-1R (6-POINT REDUNDANT)		TUG NON-TUG Σ	181.3 500.7 682.0	82.3 227.3 309.6	-475.0 -190.3 -665.3	-215.7 -86.4 -302.0

Figure 4.2-82. Final Weight Performance Comparison

Orbiter interfaces for the Tug and any associated spacecraft. It is presented in two parts: 1) the selection, including supporting rationale, of a recommended support concept for Tug plus any cantilevered spacecraft weighing no more than the 11000 lb (4994 kg) reference spacecraft (Section 4.2.1.4), and 2) an assessment of support techniques for any spacecraft weighing more than the reference spacecraft.

4.2.4.1 Tug Support Concept Selection. The structural support arrangement recommended for Tug is the six-point configuration depicted in Figure 4.2-83. It is a doubly redundant arrangement that incorporates additional Y and Z supports (one each) in excess of the minimum quantity necessary in a statically determinate system. It does not require load-balancing provisions to isolate the Tug from the effects of Orbiter relative deflection and/or stiffness. Three of the six supports are located on a common frame near the forward end of the Tug body (at X_0 951), whereas the remaining three (aft) supports are all located on the Tug deployment adapter (D/A). This adapter is Tug-peculiar peripheral equipment that remains attached to the Orbiter during Tug deployment. Tug mission performance is enhanced by locating heavy items, such as the three aft support installations, on the D/A, to take advantage of its low performance penalty partial (approximately one-seventh that of the Tug itself). The D/A structure also permits partial distribution of the point axial (X) Orbiter support loads into a cylindrical shell aft of the Tug/adapter separation plan (X_0 1172.9), thereby minimizing peaks in Tug shell load intensity. This results in a reduced

Table 4.2-50. Updated Weight/Performance Summary

Items	Support Arrangement					
	1-1	1-1A	2-1	2-1R	4-1	4-1R
Tug Body						
Sidewall	67.8	64.8	36.6	39.3	31.4	33.7
Frames	52.1	73.4	44.0	47.3	50.3	58.1
Longerons	21.5	18.5	21.5	21.5	13.5	14.8
I/F Fittings	32.8	50.5	56.6	57.0	74.1	74.2
Σ Tug, lb	174.2	207.2	158.7	165.1	169.3	181.3
(kg)	(79.1)	(94.1)	(72.0)	(75.0)	(76.9)	(82.3)
Δ PL, lb	-456.4	-542.9	-415.8	-432.6	-443.6	-475.0
(kg)	(-207.2)	(-246.5)	(-188.8)	(-196.4)	(-201.4)	(-215.7)
Non-Tug						
Adapter						
Sidewall	36.4	28.8	25.0	27.0	20.9	21.9
Frames	113.1	78.5	101.6	102.3	90.8	86.6
Longerons	33.1	28.2	33.1	33.1	20.1	22.3
I/F Fittings	189.5	139.2	183.5	183.9	140.9	142.9
Orbiter Mounted						
Bridge Beams	0	0	139.0	139.0	217.0	227.0
Load Bal Sys.	0	0	111.7	0	313.8	0
Σ Non-Tug, lb	372.1	274.7	593.9	485.3	803.5	500.7
(kg)	(168.9)	(124.7)	(269.6)	(220.3)	(364.8)	(227.3)
Δ PL, lb	-141.4	-104.4	-225.7	-184.4	-305.3	-190.3
(kg)	(-64.2)	(-47.4)	(-102.5)	(-83.7)	(-138.6)	(-86.4)
Totals Σ Δ W, lb	546.3	481.9	752.6	650.4	972.8	682.0
(kg)	(248.0)	(218.8)	(341.7)	(295.3)	(441.7)	(309.6)
Δ PL, lb	-597.8	-647.3	-641.9	-617.0	-748.9	-665.3
(kg)	(-271.4)	(-293.9)	(-291.4)	(-280.1)	(-340.0)	(-302.0)

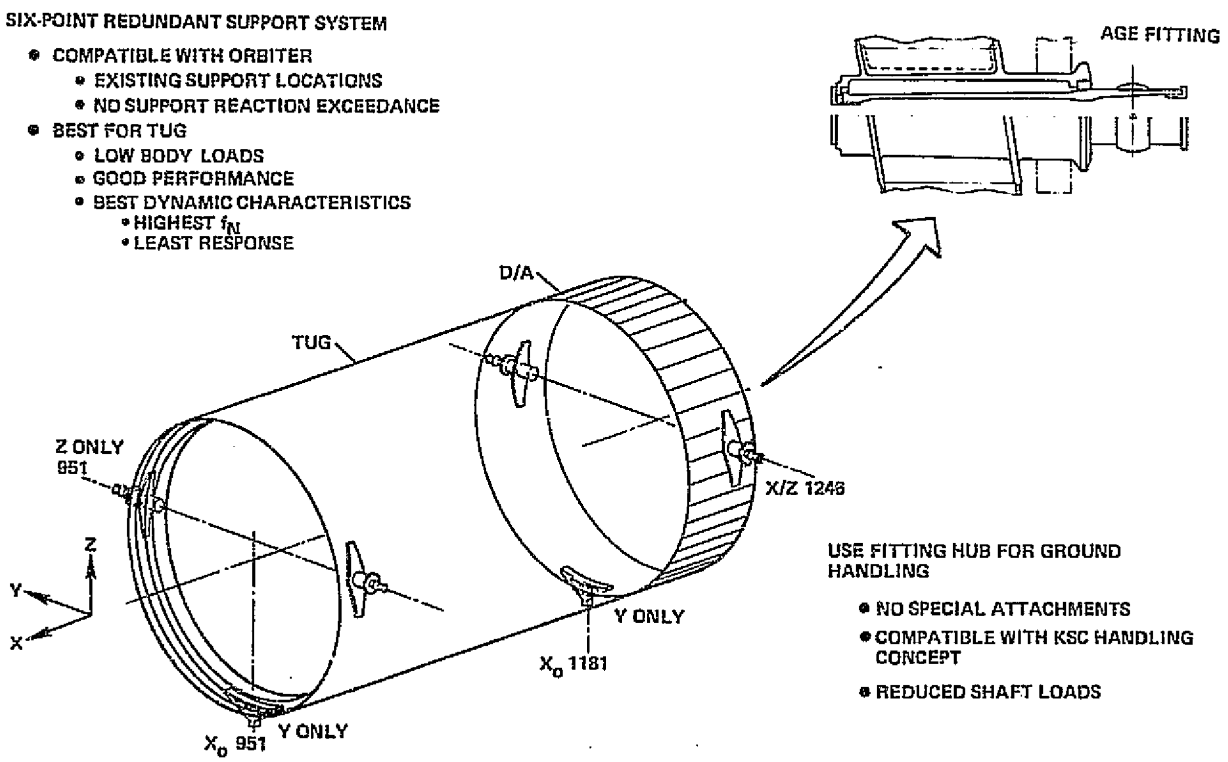


Figure 4.2-83. Recommended Structural Interface

requirement for Tug shell local reinforcement, further enhancing performance. In addition the D/A serves as a convenient mounting location for support/servicing equipment including umbilical panels, dump pressurization, and interface electronics.

Selection of the recommended six-point redundant support arrangement resulted from comparative evaluation of the six candidates shown in Figure 4.2-84.

The major evaluation criteria used in the selection process were: Tug Δ-weight and Δ-payload capability, Tug/Orbiter clearance loss due to Tug dynamic response, natural frequency of Tug plus Spacecraft in the lowest vibration mode, and support reaction compatibility with Orbiter capability. The qualitative criteria used initially in the preliminary screening selection (Section 4.2.2.4) were either quantified (dynamic response) or deleted (cost and reliability). The deletion of the latter criteria was based on prior elimination of rotation aid and nonrotating deploy (i.e., non-adapter) concepts, which were the only ones judged slightly better in these categories (Section 4.2.2.4, Figure 4.2-34). Among the retained evaluation criteria, dynamics, reaction exceedance, and Δ-payload were assumed to be approximately equal in importance with a slight weighting in the sequence given. Delta-weight was judged lower in importance since its most important effect is the impact of its distribution (Tug versus D/A) on Δ-payload, which is evaluated separately. To some extent, however,

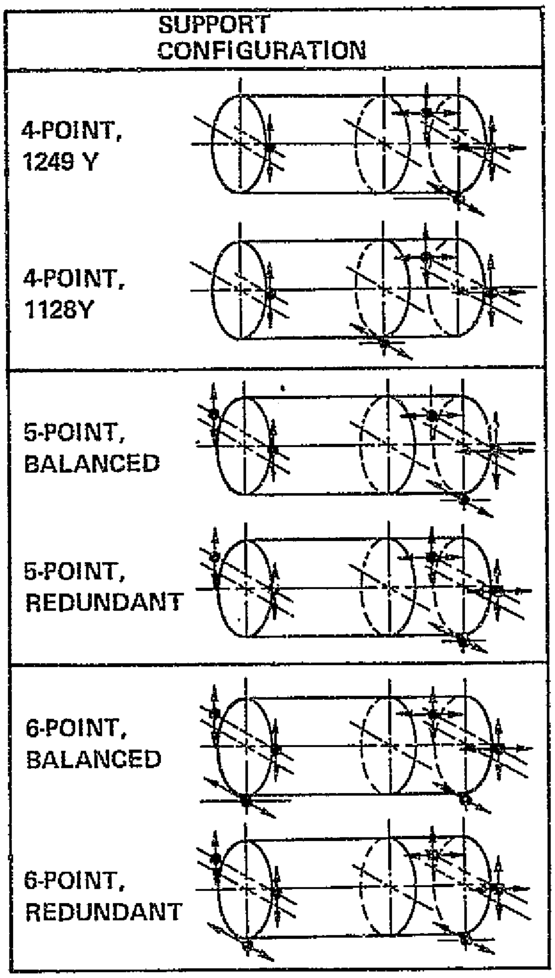


Figure 4.2-84. Support Arrangement Candidates

Δ-weight implies a minor cost distinction between the various candidates and was retained for that reason.

The comparative evaluation of candidates is given in Table 4.2-51. Delta-weights represent the sum of all elements varying in weight as a function of support arrangement, and are therefore computed relative to the following Tug/adapter and Orbiter baselines:

a. The Tug and adapter body consists of a uniform minimum gage sidewall (Section 4.2.1.1, Figure 4.2-5) without local reinforcement, with all major frames, latch longerons, and interface fittings omitted.

b. The Orbiter includes the four supports not charged to the Tug (three bridge beams and one keel fitting) but does not include additional bridge beams or load-balancing systems.

Delta-weight and Δ-payload (for a deployment mission to synchronous orbit) data is taken from Section 4.2.3.10. Dynamics data is taken from the modal and forced response analyses of Section 4.2.3.6. In those support arrangements for which specific dynamic analyses were not conducted (4-1: modes and forced response; 2-1, 2-1R: forced response) values were assigned based on similarity with arrangements that were analyzed. For example, the displacement response in both five-point systems (2-1, 2-1R) should be approximately the same as that for 1-1 since it is measured in a direction in which the first (yaw) mode effect dominates, the frequency of this mode is essentially identical among the three arrangements, and the Y-support lies at the same location (X_0 1249) in each.

Support reaction data is taken from Section 4.2.3.8. The quoted values represent the accumulated exceedance and include allowance for crash loads (based on the quasi-limit load condition and Orbiter -X capability of 110 thousand pounds (489 kN) shown in Figure 4.2-66).

Table 4.2-51. Final Support Arrangement Evaluation and Selection

Support Arrangement Candidates	Evaluation Criteria													Select
	Δ-Weight(1)			Δ-Payload(1)			Dynamics					Reaction Exceedance		
							Displacement(2)			Freq. (3)				
	lb	kg	rank	lb	kg	rank	in.	cm	rank	Hz	rank	Amt(4)	rank	
Four-Point														
1249 Y (1-1)	546.3	248.0	2	-597.8	-271.4	1	12.2	31.0	4	3.33	6	122.8	6	
1128 Y (1-1A)	481.9	218.8	1	-647.3	-293.9	4	1.4	3.6	3	3.46	3	16.2	3	
Five-Point														
Balanced (2-1)	752.6	341.7	5	-641.9	-291.4	3	12.2	31.0	4	3.36	5	118.8	4	
Redundant (2-1R)	650.4	295.3	3	-617.0	-280.1	2	12.2	31.0	4	3.39	4	118.8	4	
Six-Point														
Balanced (4-1)	972.8	441.7	6	-748.9	-340.0	6	>0.2	>0.5	2	<5.4	2	0	1	
Redundant (4-1R)	6[illegible].0	309.6	4	-665.3	-302.0	5	0.2	0.5	1	5.41	1	0	1	√

Notes:
1. Weight and synchronous deployment payload Δ relative to Tug and Orbiter each lacking all elements varying as a function of support arrangement.
2. Displacement in yaw (±Y) direction at Tug/Spacecraft Interface (X_o 936)
3. Natural frequency of lowest vibration mode.
4. Accumulated exceedance relative to Orbiter capability. Includes "quasi-limit" crash condition and assumes Orbiter -X capability of 110 klb (489 kN).

The following rationale was used in selection of the recommended arrangement:

a. Three of the six systems (1-1, 2-1, 2-1R) were unacceptable in terms of support reaction exceedance; consequently, they were deleted.

b. Of the three remaining systems 4-1 and 4-1R exhibited no exceedance and 1-1A exhibited little enough that it might conceivably have been accommodated with little or no Orbiter modification. Therefore no further screening was done based on exceedance.

c. Of these systems, displacement response in all three was acceptable (since the nominal Tug/Orbiter static radial clearance is 2.0 in. (5.1 cm)). However, 1-1A was again marginal since the stated displacements did not include any Tug body noncircularity, which would nonetheless occur due to proximity of the Tug forward support frame (X_O 951) to the displacement location (X_O 936).

d. In terms of Δ-payload, 1-1A and 4-1R were similar whereas 4-1 exhibited a greater penalty, primarily due to load-balancing system effects. Consequently, 4-1 was deleted.

e. The four-point system, 1-1A, exhibited a 200 lb (91 kg) weight advantage over 4-1R, which suggested a potential cost advantage tending to balance the marginal ratings in Items a and b above. However, review of the ingredients to the Δ-weight summations (Section 4.2.3.10) indicated that the entire difference was due to the additional Orbiter bridge and keel beams required by 4-1R. These were expected to be identical to others already in use (i.e., same as at other Tug locations, plus used by various other Orbiter cargos), and therefore would represent a negligible program Δ-cost.

f. The six-point system (4-1R) exhibited a distinct advantage in minimum natural frequency, which was particularly significant since the Orbiter forcing functions were not yet known and maximum separation (i.e. higher Tug frequency) was essential to minimize response. Consequently 1-1A was deleted, and 4-1R was selected as the recommended support arrangement.

Considerable Interface Study effort was also allocated to evaluating Tug fitting structural requirements for both in-house generated and NASA agency proposed concepts (Sections 4.2.3.3 and 4.2.3.4). The recommended sidewall fitting concept, illustrated previously in Figure 4.2-83, uses an external cylindrical hub to provide maximum outboard bearing support for the smaller diameter, replaceable primary shaft. This minimized shaft bending moments and permitted minimum weight of high-density shaft material. In addition the hub provides a surface for direct pick-up by site AGE for both horizontal and vertical handling. This approach eliminates the need for special attachment provisions and is compatible with the latest NASA-KSC handling concept.

4.2.4.2 <u>Large Spacecraft Support.</u> Section 4.2.1.4 presented the rationale for selecting an 11,000 pound (5,000 kg) reference spacecraft (S/C) for subsequent use in determining structural support reactions and Tug structural sizing. However, the then-current mission model included planetary spacecraft whose weights exceeded the reference S/C and for which support was required. This section compares four candidate techniques for supporting these S/C. The largest S/C in the mission model (PL-02-A, W=18523 lb or 8409 kg) was used for reference in this comparison. All support reactions were computed using accelerations per MSFC 68M00039-1.

As shown in Figure 4.2-85, in both cantilever concepts support reactions generally exceeded those for the 11,000 pound (5,000 kg) reference S/C indicating additional weight penalties to both Tug and Orbiter to accommodate heavier S/C. The extent of exceedance was a function of support arrangement configuration but was largest for those with a single forward Z support. This resulted primarily from the more forward cg location, characteristic of heavy S/C during both ascent and abort descent mission phases, and indicated that a fourth Z support was mandatory for these concepts. Both cantilever concepts were also "soft" dynamically and were expected to exhibit significant clearance loss at maximum response, which in turn would impose a reduction in their permissible static envelope diameter.

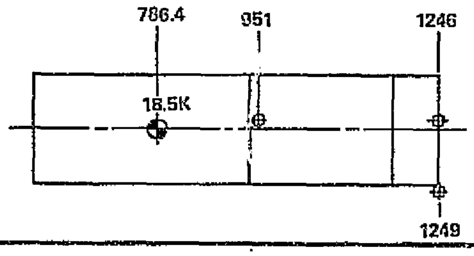
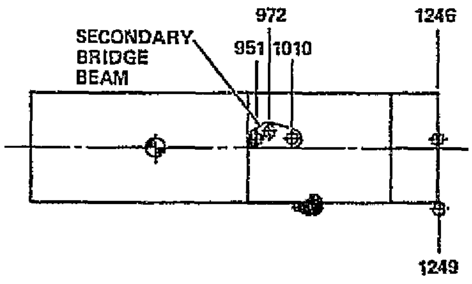
SUPPORT CONCEPT	COMMENT
CANTILEVER — BASELINE 	• SUPPORT REACTIONS SUBSTANTIALLY EXCEED ORBITER CAPABILITY, GENERALLY EXCEED THOSE FOR REFERENCE S/C • ADDITIONAL ORBITER, TUG Δ-WEIGHT • 4 Z-SUPPORTS MANDATORY • SIGNIFICANT S/C DYNAMIC CLEARANCE LOSS
CANTILEVER — SECONDARY BRIDGE 	• Z-SUPPORT REACTIONS HIGHER THAN BASELINE • LOAD ON ORBITER FRAME STILL EXCEEDS CAPABILITY • FURTHER TUG Δ-WEIGHT • 4 Z-SUPPORTS MANDATORY • 7 STANDARD + 2 SECONDARY BRIDGE BEAMS • SECONDARY BEAMS HEAVY, TRUNNION & CAPTURE MECHANISM HARD TO INTEGRATE • SMALL INCREASE IN PITCH CLEARANCE LOSS

Figure 4.2-85. Cantilever Concepts for Large Spacecraft Support

The secondary bridge concept attempted to minimize Orbiter impact at the forward supports by employing dual forward Z supports and distributing their associated trunnion loads to three Orbiter mid-fuselage frames through a secondary bridge beam supported in turn by two adjacent standard bridge beams. The concept required a total of seven standard bridge beams plus two special secondary beams. The Orbiter frame at Station X_O 979.5 had to provide support for both adjacent standard bridge beams. Although significantly reduced by the multi-beam system, the load applied to this frame still exceeded Orbiter capability. In addition, the pitch (Z) reactions were increased slightly in comparison with the baseline cantilever concept due to reduction in fore/aft span between pitch reactions. This span reduction also increased the required allowance for dynamic clearance loss in the pitch plane.

Secondary bridge beams were also difficult to integrate without further Tug and Orbiter impact. If placed above the standard beams in the Y_O ±94 plane to preclude additional twist of standard beams, the trunnion elevation had to be increased to provide adequate secondary beam section depth for both strength and deflection. If kept shallow to minimize the elevation change, they became very heavy. Conversely, if placed inboard of the standard beam to maintain the same trunnion elevation they violated the present Tug clearance envelope, requiring Tug diameter reduction, and produced additional loads on Orbiter frames due to increased lateral eccentricity of the trunnion.

Due to penalties associated with cantilever support concepts, the two alternative concepts shown in Figure 4.2-86 were investigated and recommended for further study. Primary advantages of both alternative concepts were reduced S/C dynamic clearance loss, reduced support reactions, and potential S/C structural weight reductions.

The first system incorporated auxiliary supports directly between the S/C and Orbiter to provide additional restraint for the Tug - S/C combination. These supports could take either of two forms: attenuators, whose primary function was limiting dynamic response; or rigid supports, which augmented the basic Tug supports by providing redundancy. The rigid supports might also have been mechanized in conjunction with basic Tug supports to permit selective engagement/disengagement for critical mission phases (e.g., abort descent). As a maximum, eight standard Orbiter bridge beams (five for Tug, three for S/C) were required for this concept.

The second alternative concept consisted of independent structural support for Tug and S/C. For a four-point S/C support system, using the support locations shown, resulting reactions were within Orbiter capability. Furthermore, due to the propellant off-load for a heavy payload deploy mission, reactions for a four-point Tug support system were less than those for a Tug with five supports on a retrieval ascent mission, with one exception (Z_1). However, the X/Z interaction at this location was still within specified Orbiter capability. It was therefore permissible to install the Tug with four supports for this mission (even though five were required for other missions). As a result, eight standard bridge beams were required and no additional Tug or Orbiter weight penalties were imposed in this concept.

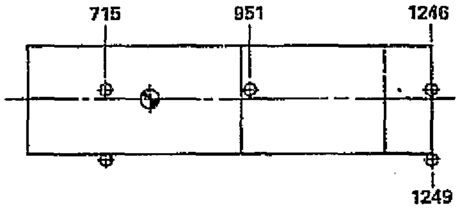
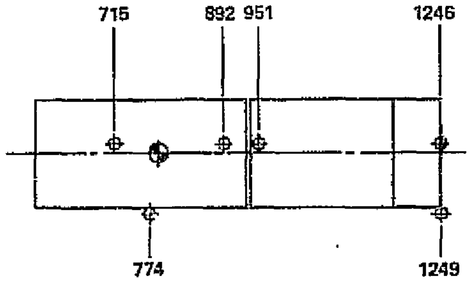
SUPPORT CONCEPT	COMMENT
AUXILIARY (ATTENUATORS OR RIGID)  	• SUPPORT REACTIONS REDUCED (MAGNITUDES DEPEND ON SUPPORT STIFFNESS) • 7-8 STANDARD BRIDGE BEAMS • SUBSTANTIAL REDUCTION IN S/C CLEARANCE LOSS • S/C AFT STRUCTURAL WEIGHT REDUCED • RECOMMENDED FOR FURTHER STUDY
INDEPENDENT TUG, S/C  	• REACTIONS WITHIN ORBITER CAPABILITY FOR 4-PT S/C SUPPORT • TUG SUPPORT REACTIONS LESS THAN RETRIEVAL ASCENT CONFIG, 4-PT SUPPORT POTENTIALLY PERMISSIBLE • NO ADDITIONAL ORBITER, TUG Δ-WEIGHT • 8 STANDARD BRIDGE BEAMS • MINIMIZES S/C DYNAMIC CLEARANCE LOSS • REDUCES S/C AFT STRUCTURAL WEIGHT • PERMITS USE OF SHROUD AS ORBITER-RETAINED STRUCTURAL CRADLE • REQUIRES ON-ORBIT TUG – S/C MATING PRIOR TO DEPLOYMENT • MINIMIZES QTY, STRENGTH OF TUG – S/C LATCHES • MAY PERMIT INDEPENDENT CHANGE-OUT • RECOMMENDED FOR FURTHER STUDY

Figure 4.2-86. Non-Cantilever Concepts for Large Spacecraft Support

Independent Tug - S/C support required on-orbit structural mating of the two vehicles prior to deployment. However, Tug-supplied S/C services could be connected at the time of initial installation in the Orbiter by providing flexibility (if necessary) at the Tug - S/C forward umbilical panel. Since inertia loads during deployment and Tug flight were significantly less than those during Orbiter operations, the quantity and strength of Tug - S/C structural interface latches could be minimized, resulting in S/C aft structure weight reduction. Independent support could also provide for independent change-out of either vehicle. This concept also permitted use of a contamination shroud (if required) as an Orbiter-mounted structural cradle to minimize S/C flyaway weight.

4.3 MECHANICAL INTERFACE

The Space Tug must be supported by Shuttle during launch, atmospheric flight, reentry and landing, released during deployment, and recaptured at mission completion. Mechanisms are required to engage/disengage structural latches and umbilical panels as well as accomplish Tug deployment and recapture. Interface mechanisms have been identified through functional analysis of the various mission phases. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into the Orbiter. The entire Tug, adapter, and umbilical support are installed as an autononous unit into the Orbiter.

During the course of the study, the installation configuration of the mechanisms changed as the requirements were refined. A goal of the study was to incorporate all required functions with minimum impact on the Orbiter. The selected concept, shown in Figure 4.3-1, requires umbilical panels, pivot actuators, Tug-adapter latches, alignment guides, TV cameras, and RMS attachments for interface between the Tug and the Orbiter. The individual mechanisms do not directly interface with the Orbiter and are therefore defined by functional requirements only. Detail design of these mechanisms remains for the Tug development phase. A description of the selected concept mechanisms follows.

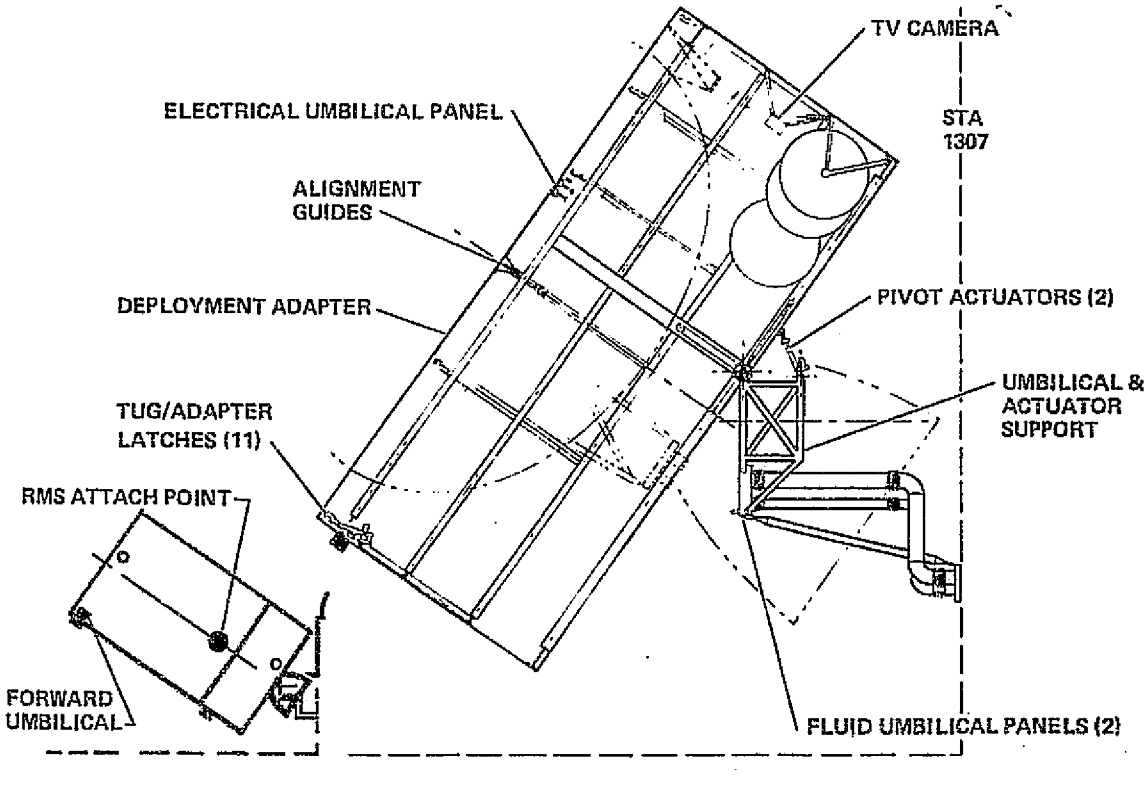


Figure 4.3-1. Mechanical Interface

The mechanisms are mounted on the deployment adapter and two umbilical support trusses. The support trusses are pivot mounted to the deployment adapter, concentric with the Station 1246 support. Umbilical separation forces are reacted through the pivot and also through a strut attached to the Station 1307 fluid interface panels. Umbilical misalignments are allowed by limited travel bellows at each disconnect.

The fuel umbilical support incorporates attachments to mount the adapter pivot actuators. Forces exerted on the deployment adapter by the pivot actuators are sufficient to disconnect and reconnect the umbilicals. The large moment arm to the forward umbilical panel prevents the pivot actuators from reliably disconnecting the forward umbilicals hence requiring its separation before rotation.

Tug-adapter latches are essentially the same over-center mechanism presented in the NASA baseline Tug documentation with the exception of a cam face addition to actively separate the Tug from the adapter. This latch separation force is used to disengage shear pins and the C&W electrical umbilical.

An Orbiter-supplied TV camera is located in the deployment adapter to provide monitoring of alignment during deployment and retrieval. The TV views a target on the Tug. The Tug umbilical panel supports and the target supports are designed to provide mechanical centering and guidance of the Tug during retrieval. Progressive terminal alignment is provided by the latch mechanism and shear pins.

The selected interface concept was derived by comparing several different approaches. Evaluation of alternative interface concepts was accomplished by trade and optimization studies to determine baseline Tug/Payload detailed subsystem interface requirements. Trade studies evaluated subsystem interface options using several criteria. Cost, weight, performance, and reliability were evaluated quantitatively. Safety, risk, and interface simplicity were evaluated qualitatively. Safety was an absolute criterion. In most mechanism areas, interface simplicity and reliability were the determining criteria. Interface cost (DDT&E) and performance effects were less significant since their contribution to total system cost and performance was relatively small.

4.3.1 <u>TUG PERIPHERAL EQUIPMENT MECHANISM REQUIREMENTS</u>. The objectives of this study task were to identify candidates for mechanical interfaces, analyze their characteristics, and present physical and functional interface requirements for selection and inclusion in the Orbiter design. An interrelationship exists between the Tug system support concept and subsystem candidate options. Suitable individual mechanism selection also depends on the Tug deployment scheme. Two methods were analyzed — lateral RMS deployment directly from Orbiter support fittings, and rotational deployment with support adapter or yoke and their corresponding influence upon individual mechanical interfaces.

In addition to the analysis of individual mechanism operation, backup actuation provisions must be included in all mechanisms that could endanger the Orbiter capability for safe reentry and landing. Of significant importance is the requirement to stow the adapter to permit payload bay door closure. Associated mechanisms must be provided with RMS or EVA actuation backup capability to allow stowage or jettison of the adapter and/or Tug in event of malfunction.

The individual mechanisms are packaged as Tug peripheral equipment and do not directly interface with the Orbiter. Because no Orbiter interface exists, their detail design remains for the Tug development phase. General requirements for the deployment adapter mechanisms are:

a. Umbilical Panels

Hold disconnects engaged against fluid pressure-loads.
Provide flexibility for flight deflections.
Disconnect fluid lines for deployment.
Align and reconnect following retrieval.

b. Pivot Actuators

Rotate and hold adapter for Tug deployment/retrieval.
Hold adapter in stowed position after expendable mission.
Power umbilical panel disconnect-reconnect.

c. Tug-Adapter Latches

Latches-unlatches Tug to adapter.
Part Tug from adapter to disengage alignment pins and electrical umbilicals.
Pulls together Tug to adapter for cinchup.

d. Alignment Guides

Guide Tug during deployment and retrieval.

e. TV Camera

Provides Y-Z alignment indication for deployment/retrieval.

4.3.1.1 Aft Umbilical Panels. Fluid and electrical services must be attached to the Tug through separable connections capable of reengagement to enable deployment and retrieval for mission achievement. Several umbilical and line options were investigated, terminating in the recommended configuration shown in Figure 4.3-2.

The arrangement is essentially identical to the NASA baseline Tug (MSFC68M00039-2) with the addition of a forward disconnect panel as proposed for Orbiter interface

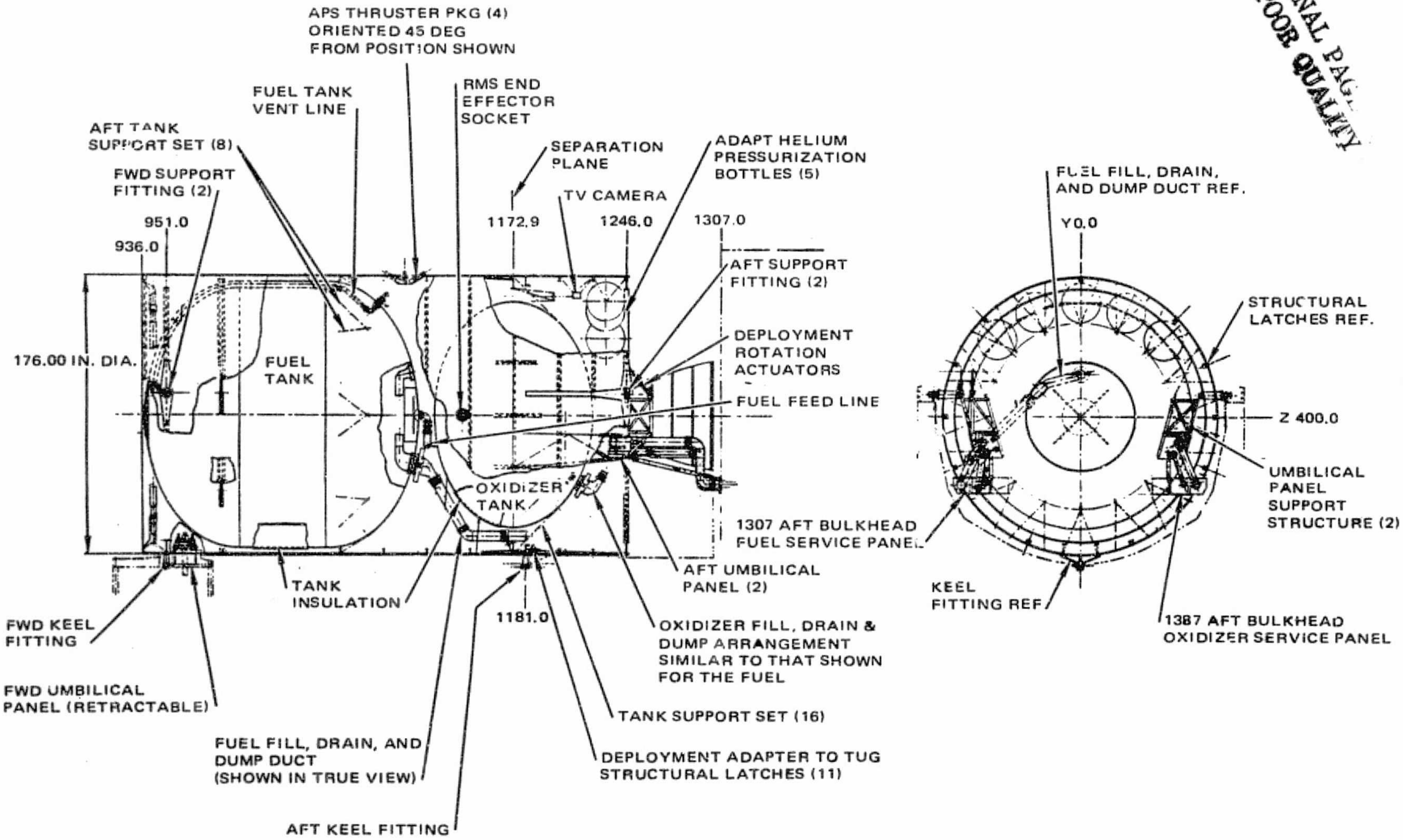


Figure 4.3-2. Umbilical Panel Configurations

revision and the relocation of the aft panels to allow for clearances during adapter rotation and Tug deployment.

In the initial Convair deployment adapter approach, umbilicals were routed from Station 1307 bulkhead through flexible connections concentric with the Tug/adapter pivot and thence to umbilical disconnect panels at the Tug/adapter interface plane, Figure 4.3-3. The advantage of the flexible fluid lines is in maintaining the connections

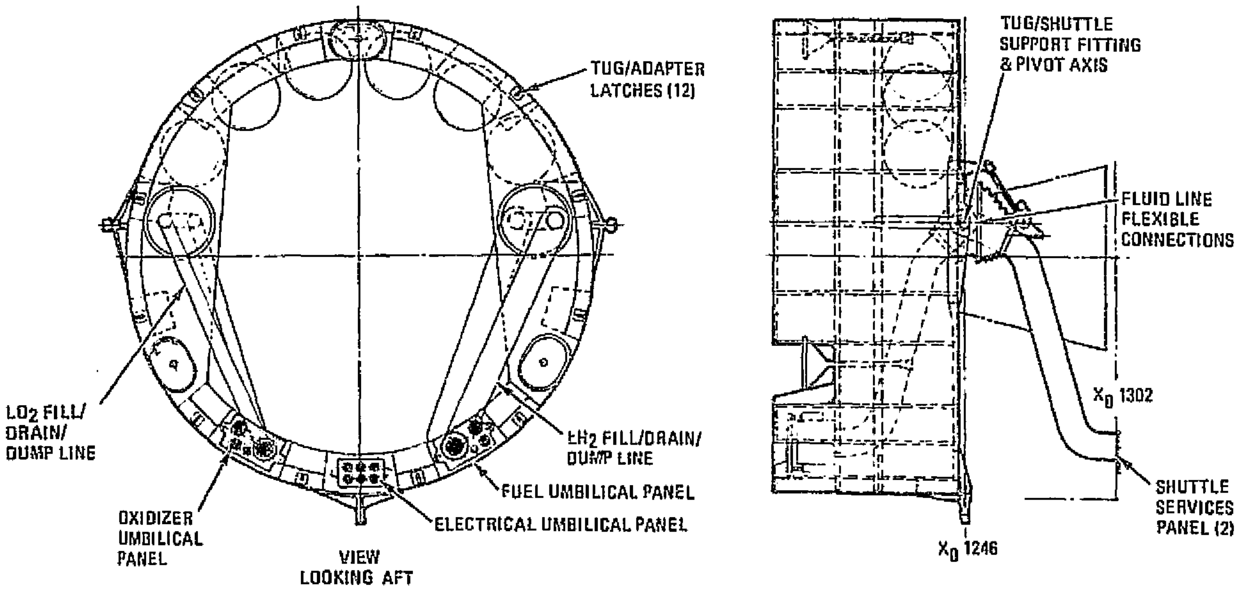


Figure 4.3-3. Initial Umbilical Arrangement

during rotation and continuously enabling propellant tank venting through the Orbiter vent lines. Reconnection of the vent and pressurization lines can be assured at the earliest possible time following Tug retrieval. Failure to reconnect the umbilicals is cause for jettisoning or abandoning the Tug. The umbilical panels require retraction/separation actuators to disengage disconnect coupling seals, which will have an unknown friction due to temperature and dimensional differences. This panel retraction force will exceed the approximately 15 pounds (66.7 newtons) force capability of the RMS available for deployment and retrieval.

An intermediate interface study deployment adapter configuration, Figure 4.3-4, incorporated a subsystem support structure. This structure was mounted between pivots on the deployment adapter (concentric with the pivot centerline) and a modified Orbiter keel fitting to provide support for the retractable fuel and oxidizer umbilical panels. The need for this support structure arose due to problems in identifying Tug peripheral equipment mounting locations on the Orbiter midfuselage structure. It became obvious that the exact locations could not be identified adequately for inclusion in the Orbiter design, thus use of a structure to bridge between existing orbiter

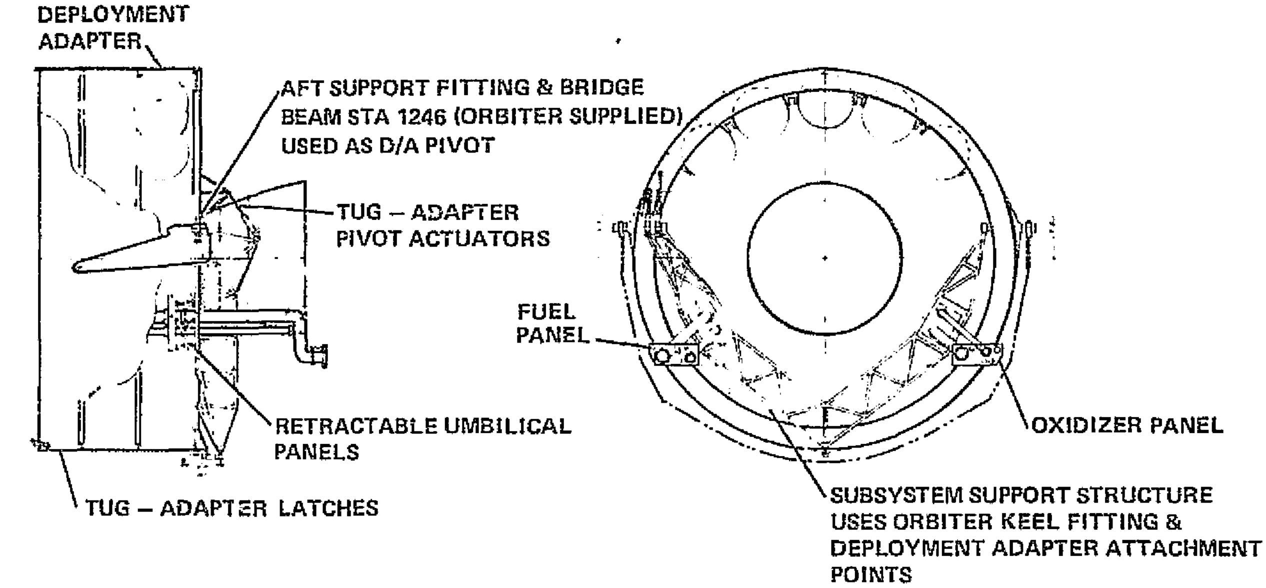


Figure 4.3-4. Umbilical Support Structure

support points was selected to provide for mounting umbilical panels and a deployment actuator reaction point. The disconnect-before-rotation concept can be questioned from a safety standpoint due to the possibility of simultaneous LH_2 and LO_2 propellant venting into the Orbiter cargo bay. As presented in Section 4.4, the pressure is too low at orbital altitudes (below 0.10 psia, 0.069 N/cm^2) to enable oxygen/hydrogen combustion when mixed in any proportion, therefore eliminating any potential safety hazard. In any case, propellant lines are inactive and unpressurized during deployment.

The advantage of this umbilical system is elimination of the requirement for fluid transfer line rotary (or lateral for a gimballed line) motion. This reduces complexity, eliminates a potential safety hazard (joint leakage) and saves weight. The concept shown in Figure 4.3-4 exhibits a weight reduction of 180 lb (82 kg) in comparison with the flexible line approach of Figure 4.3-3. Fluid line weight (length and joints) deleted 250 lb (114 kg), and the support truss added 70 lb (32 kg) to obtain the net reduction indicated.

With the Tug located in the cargo bay, RF communications for safety monitoring cannot be established thus requiring that hardwire safety monitoring be maintained through rotation. The hardwire C&W function electrical umbilicals are routed around the deployment adapter pivot and remain connected until the RF link is established following rotation. The adapter-mounted electrical umbilicals use the excess force available from the Tug to deployment adapter structural latches to provide separation and reengagement.

The recommended configuration, Figure 4.3-2, consists of individual supports for the fuel and oxidizer panels. These supports are pivot mounted from the deployment

adapter support axis, which enables close alignment control of the panels for re-engagement, independent of Orbiter to Tug deflections/tolerances. The Tug-adapter interface is precisely aligned through close tolerance shear pins, which will realign the Tug to the disconnects well within the recommended ±1.18 inch (3.0 cm) side capability of the umbilical panel alignment pins.

Axial position of the umbilical panels is maintained by struts attached to the Orbiter Station 1307 fluid interface panels. Axial misalignment requirements for the disconnects depend on deflection characteristics of the Orbiter bulkhead but are assumed to be in the order of ±1.47 inch (4.0 cm) and will be absorbed by either bellows or disconnect probe engagement, to be determined by detail design. The specific mounting technique and location chosen provides adequate alignment and acceptable forces to enable the deployment adapter pivot actuator to disengage and reengage the umbilicals simultaneously with deployment adapter rotation. This eliminates the requirement to separately retract the umbilical panels before rotation. This concept has eliminated the complexity of panel retraction mechanisms, the retraction actuators and motors, the electrical wiring, control and command system, and the inherent unreliability associated with the deleted system. This elimination of support structure and umbilical panel mechanisms resulted in a 100 pound (45.4 kg) weight reduction compared with the concept shown in Figure 4.3-4.

The hardwire electrical umbilicals pivot with the deployment adapter to provide continuous monitoring of C&W functions until RF communication is established.

4.3.1.2 Forward Umbilical Panel. Electrical and fluid services are required for Tug payloads from the Tug and also from the Orbiter/Ground. The Tug to payload services must be routed through the payload adapter. Payload to Orbiter/Ground services have three routing options: 1) through the deployment adapter, Tug, then to payload, 2) direct from Orbiter to payload, or 3) through a Tug forward panel to the payload, as illustrated in Figure 4.3-5. Since all payloads must attach to the Tug at the payload adapter interface, a common umbilical interface can easily be provided. For multiple Tug payloads, and different diameter payloads, providing umbilicals directly from the Orbiter would require many unique design configurations, which would be cost prohibitive and in conflict with the Space Shuttle System concept general philosophy. Due to this consideration, direct routing was not considered a candidate and was eliminated from contention.

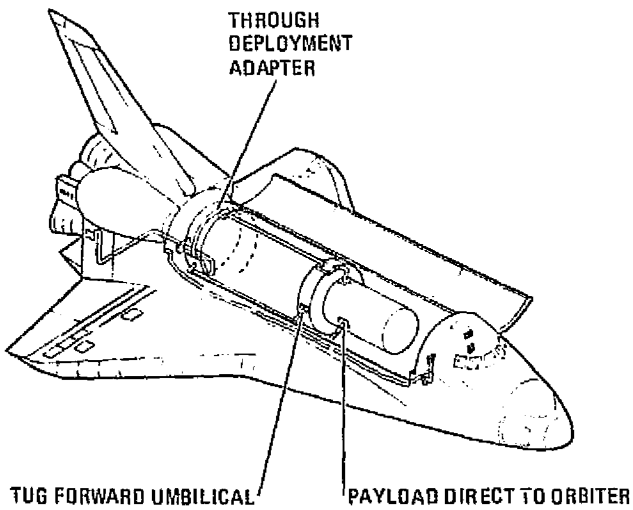


Figure 4.3-5. Payload Umbilical Options

The routings seriously considered, both of which are acceptable for Tug operations, are shown in Figure 4.3-6. Table 4.3-1 summarizes the comparative weight, line routing, and operational flexibility data for the two payload umbilical panel locations.

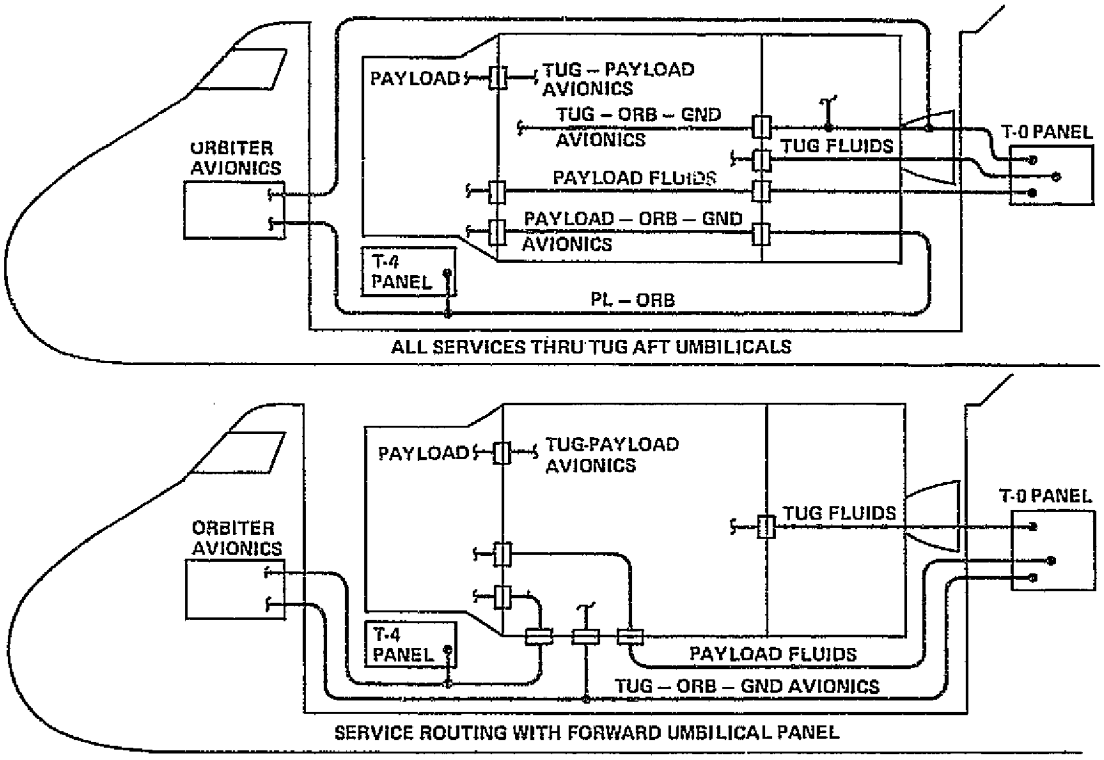


Figure 4.3-6. Umbilical Routing Comparison for Tug Payloads

In addition to payload use of the forward umbilical panel, the Tug avionics are mostly located in the Tug forward end and can use the forward panel to advantage.

The following conclusions were reached regarding the desirability of an Orbiter supplied cargo bay umbilical panel system:

a. Spacecraft require a unique number and size of fluid and electrical Orbiter connectors.

b. A forward umbilical panel on Tug can be used with easily accessible spacecraft unique fluid and wiring kits.

c. Tug avionics are mostly located at the Tug forward end; therefore Tug wiring and weight can be minimized by using the forward umbilical for Tug functions other than caution and warning.

Table 4.3-1. Payload Umbilical Comparison

Consideration	Forward Umbilical		Via Tug Aft Umbilical	
	Orbiter	Tug	Orbiter	Tug
Struct/Mech Wt, lb (kg)	100 (45)	25 (11)	10 (4.5)	8 (3.6)
Fluid Services Wt, lb (kg)	135 (61) (18 active disconnects)	20 (9)	61 (28) (24 active disconnects)	163 (74)
Elect Services Wt, lb (kg)	37 (17) (60 noncritical lines)	15 (7)	143 (65) (60 noncritical lines)	73 (33)
Total P/L Penalty, lb (kg)	260 (118)		718 (326)	
Line Routing				
Small < 1 in. (2.5 cm) dia.	Thru cargo bay raceways		Between Tug tank and shell	
Large > 1 in (2.5 cm) dia.	Outside cargo bay envelope		Not allowed	
Operational Simplicity and Flexibility	Single forward location satisfies all Tug payload reqt and also accommodates non-Tug payloads.		Different kit required for non-Tug payloads, possibly different/added kit for various Tug payloads.	
	Common interface location simplifies Orbiter design, installation and service reqt.		Different kits may require different GSE and added operations tasks.	

d. A forward Tug mounted Orbiter umbilical is recommended for the majority of Tug avionics and spacecraft services.

Multiple non-Tug payloads and payloads carried concurrent with Tug require Orbiter connections throughout the cargo bay length for caution and warning functions, hazardous fluid tank venting, and RTG coolants, as depicted in Figure 4.3-7.

The design requirements for a forward umbilical are similar to an aft mounted panel, including static and dynamic misalignment capability, load capability for pressure

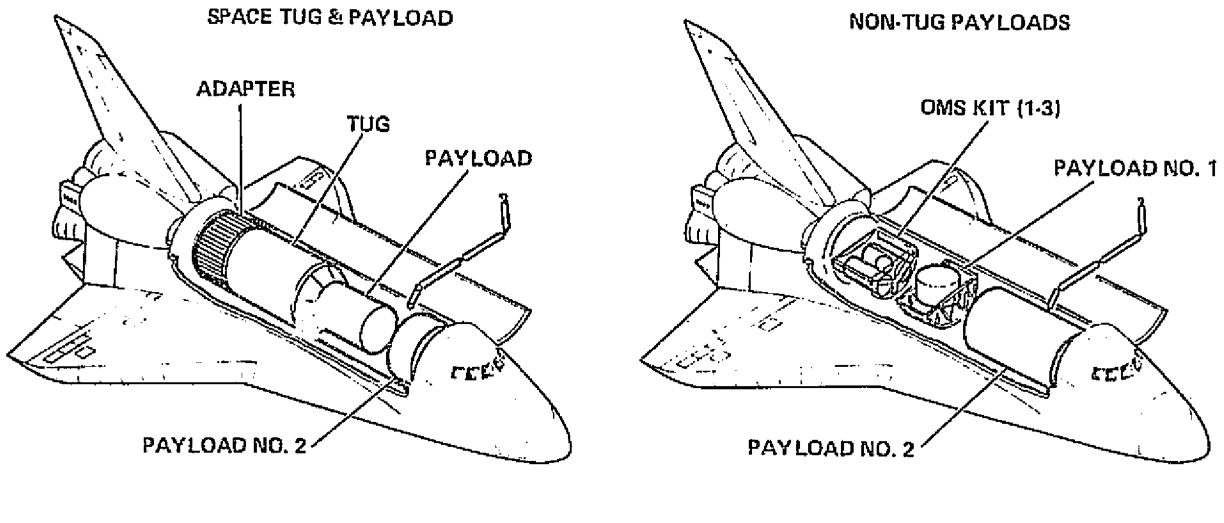


Figure 4.3-7. Multiple Orbiter Payloads

separation forces, realignment guides to enable remate engagement, and disconnect motion by an actuator system. The major single difference is the longitudinal Orbiter Xo position. To accommodate both Tug and non-Tug payloads throughout the cargo bay, nine locations for intermediate umbilical panels are recommended. These are positioned 9.83 inches (25 cm) aft of the support locations as shown in Figure 4.3-8.

Three circumferential locations, shown in Figure 4.3-9, were considered for positioning the forward umbilical panels in the Orbiter cargo bay. The recommended location is a compromise of the factors compared in Table 4.3-2. The significant advantage of each location is 1) the longeron location is readily visible, 2) the keel position uses existing support points, and 3) the intermediate position gives good line

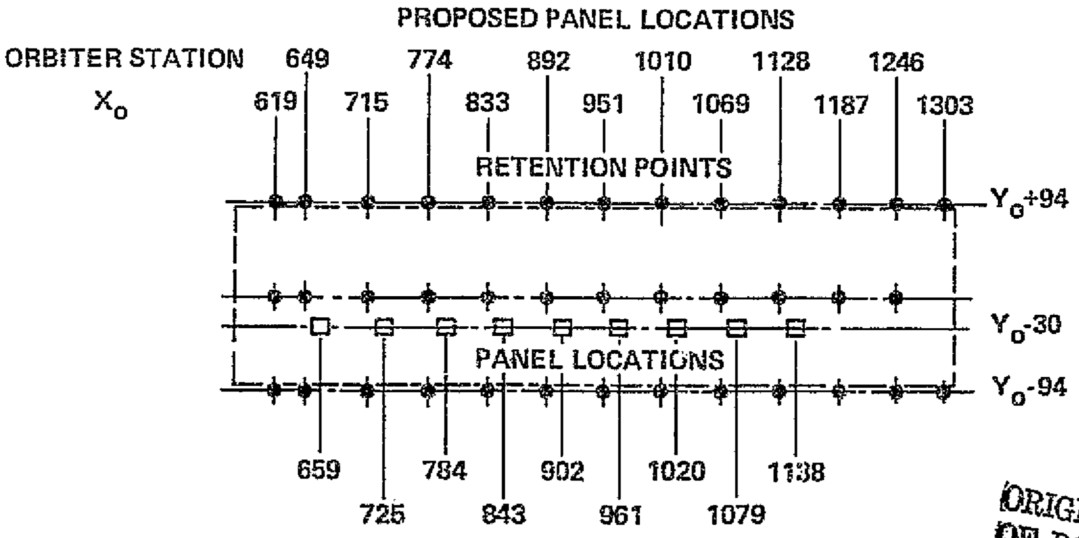


Figure 4.3-8. Recommended Panel Locations

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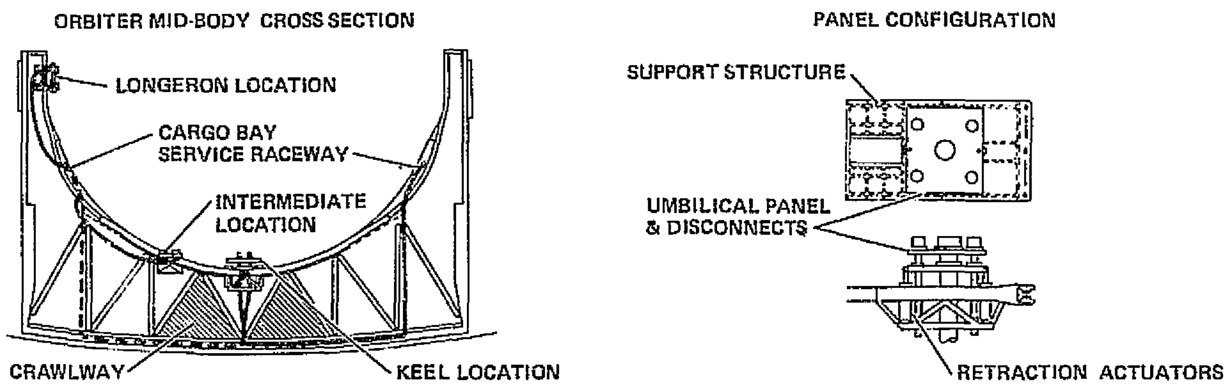

Figure 4.3-9. Forward Umbilical Panel

Table 4.3-2. Panel Location Comparison

Comparison Factor	Longeron	Keel	Intermediate
Installation	New Orbiter support points required. Installation depth questioned	Mounts from modified keel bridge beam to existing Orbiter support points	New Orbiter support points required
Cable/Tube Routing	Short route to service raceway	Routing around crawlway is difficult	Short route to service raceway
Access	Umbilicals are visible via RMS TV for inspection	Visual inspection not possible	Visual inspection not possible
Disconnect Operation	Jammed umbilical panel prevents deployment	Payload will separate if panel fails to retract	Payload will separate if panel fails to retract
EVA Assist	Possible due to location	Not possible	Not possible

routing without interfering with the crawlway space. The intermediate location at Orbiter Y_0 Station-30 inches (-76 cm) was chosen based mainly on the advantages gained by cable/tube routing and redundant disconnect operation. These factors reduced installation complexity and increased the chance of mission success respectively. The weight of the forward umbilical panel would be chargeable to the Tug peripheral equipment or to each non-Tug payload for which a panel is installed.

4.3.1.3 Pivot Mechanism. The selected deployment adapter structural support configuration requires initial Tug rotation to provide the axial clearance for lateral extraction of Tug and its engine nozzle from the adapter. Functions to be provided by the pivot mechanism are:

a. Rotate adapter, Tug and spacecraft for deployment.

b. Hold deployment adapter in position during deployment.

c. Rotate deployment adapter less Tug into cargo bay as required for Orbiter space operations.

d. Hold deployment adapter in stowed position for entry and landing following expendable Tug mission.

Two power sources are potentially available for the pivot mechanism. The Orbiter's remote manipulator system (RMS) can be attached to the front of the Tug and provide the force for rotation, or a Tug peripheral equipment actuator can be employed. Use of the RMS would require additional mechanisms to hold the adapter in the up position so that the RMS can deploy the Tug. A holding device or position lock would also be needed to hold the deployment adapter in the landing position when there is no Tug attached. RMS cannot be used at this time since it must be stowed to allow cargo bay door closure.

A mechanical actuator system can provide all four of the required rotation functions, leaving the RMS free for other scheduled and backup tasks. Pivot actuators located between the umbilical support structure and the deployment adapter, Figure 4.3-10, are recommended as presented in Table 4.3-3. The redundant actuators, powered simultaneously to effect rotation, are both located on the fuel side (port) umbilical support so that the RMS, when equipped with a special end effector, may be used to disconnect either actuator in the event of failure. In its present configuration RMS cannot reach the similar position on the right-hand side of the orbiter.

An investigation to determine the optimum pivot location for Tug was performed as part of the pivot mechanism study. Actual pivot location selection was made from structural support criteria as presented in Section 4.2. The forward end of the baseline Tug was located at Station 936, which consists of a 360-inch (914.4 cm) Tug plus 6-inch (15.2 cm) clearance to the Station 1302 clearance envelope. The RL 10 engine nozzle was assumed to be 70 inches (177.8 cm) in diameter.

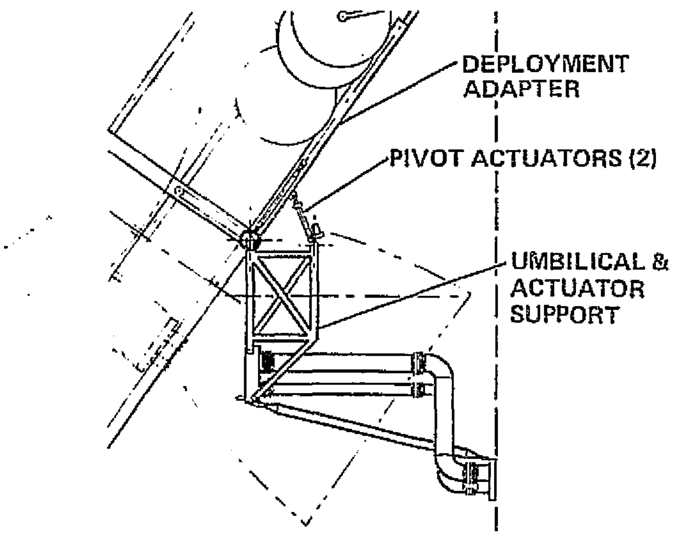

Figure 4.3-10. Pivot Actuators

As the Tug and adapter are pivoted, the engine nozzle swings through an arc that approaches the aft bulkhead envelope at Station 1302, then the cargo bay lower envelope at Waterline 310. The Tug was moved forward or aft until the engine nozzle was tangent to one or both of the envelope clearance lines. The results obtained from varying the pivot station are presented in Figure 4.3-11. From Station 1206 to 1302 the clearance is controlled by the aft bulkhead envelope, while at stations forward of 1206, the cargo bay lower envelope determines the Tug position in the bay. The Tug forward station parameter was obtained geometrically by calculating the dimension the Tug must be moved for the engine to be tangent to the envelope when pivoted for deployment. For example, if a 45-degree ($\pi/4$ radian) pivot is required about Station 1128, the Tug must be moved 11 inches (27.9 cm) forward from its nominal position to Station 925 to provide clearance with the cargo bay Waterline 310 envelope. The indicated forward relocation is undesirable from a program standpoint since an equal length must be subtracted from the useful payload. The effect of Waterline location change is presented in Figure 4.3-12 and is interpreted in a similar manner.

The third parameter to be considered is the angle through which the Tug will be rotated for deployment. The minimum angle that provides Tug clearance at the Orbiter forward bulkhead when extracted from the adapter is approximately 16 degrees (0.28 radian). Visibility for RMS operation while reinserting the Tug into the adapter

Table 4.3-3. Pivot Mechanism Selection

Requirement	Selected Concept	Alternative Concepts
Actuator Type	Linear Actuator	Rotary or RMS
Power Source	Electrical	Hydraulic/Pneumatic
Number of Actuators	Two	One
Location	Both on Left Side	One on Each Side
Position Lock	In Actuator	Separate Mechanism or RMS

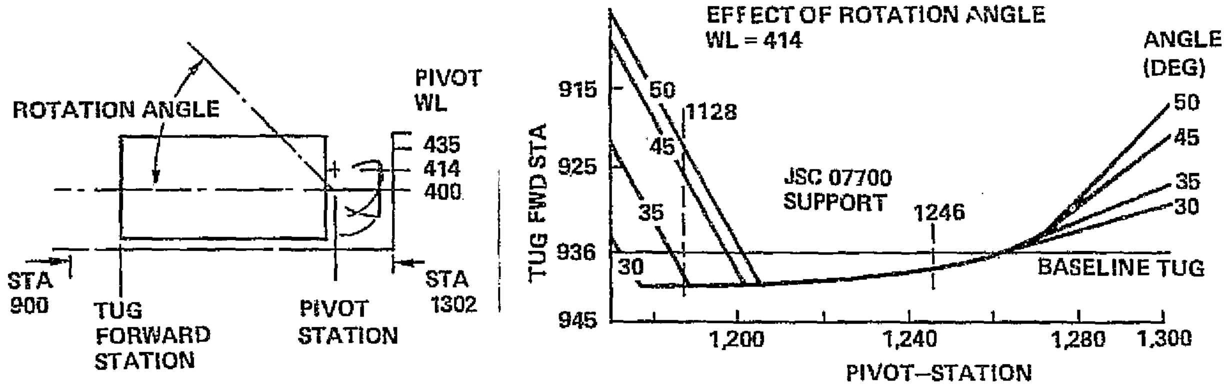

Figure 4.3-11. Pivot Support Station

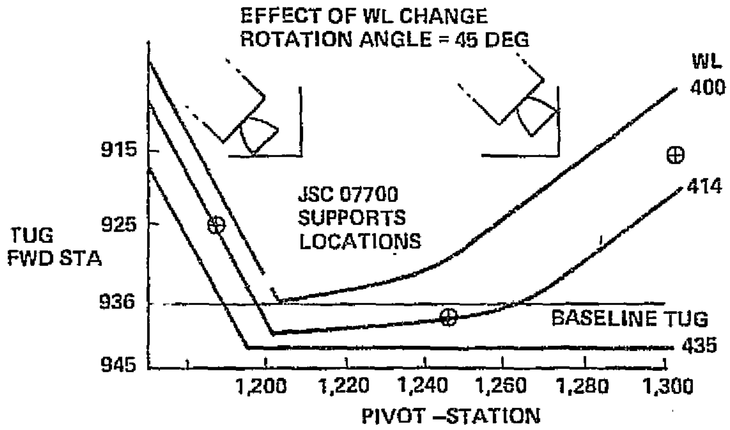

Figure 4.3-12. Pivot Support Waterline

favors about 25 degrees (0.44 radian). The criteria used to select the pivot angle concerns the antenna location on the Tug and Orbiter for RF communications. At present, RF transmission in the cargo bay is prohibited and RF is required to establish the safety, command, and monitor link before separating the hardwire umbilical. Rotation of 35 degrees (0.61 radian) will enable communications between the Tug and Orbiter, thereby establishing the pivot angle.

4.3.1.4 Tug Adapter Latches. Structural latches are required between the Tug and deployment adapter to carry the loads incurred during ground and flight mission phases. Initially, 16 latches were evenly spaced at π/8 increments. As a result of the structural finite element modeling (Section 4.2), it was shown that 93 percent of the load transfer between the Tug and adapter occurs through the eight latches adjacent to the aft X/Z support fitting longerons. This implied that the majority of the other eight latches could be eliminated. Three stabilizing latches have been retained, as shown in Figure 4.3-13, one on the top centerline and two stradling the bottom centerline and the Y support fitting. The 11 support latches are still located at π/8 increments.

Detail design and sizing of the latches depends on the final configuration of the Tug and adapter. General requirements for the latch are outlined below and combined in the predesign arrangement shown in Figure 4.3-14.

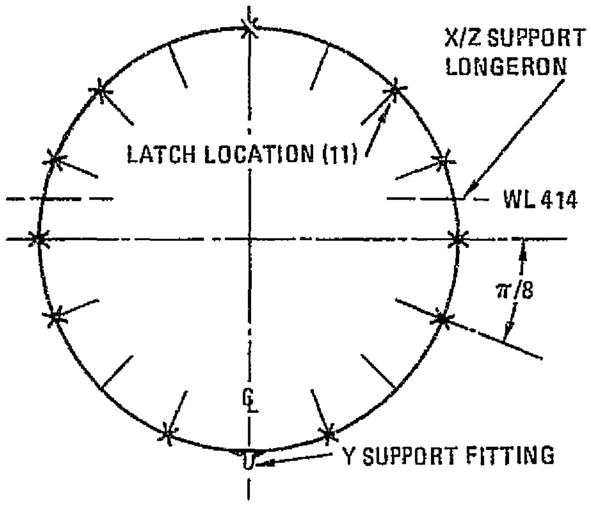

Figure 4.3-13. D/A Latch Location

a. In order to distribute loads from the latch to the structural shells of the Tug and adapter, longeron fittings are required at each latch.

b. Present estimates are for a limit latch load of 20 kilopounds (89 kilo-Newtons) each.

c. Shear pins are required for side load transfer between the Tug and adapter.

d. The latch must have a positive force capability to push the Tug away from the adapter. This force must be applied to disengage the shear pins and electrical umbilical, and act over an approximate 0.4 inch (1.0 cm) stroke.

e. For reconnection following RMS retrieval, a pull together capability of approximately 0.8 inch (2.0 cm) is required to provide terminal alignment, engage the shear pins and electrical umbilicals, and provide latch preload.

f. Structural redundancy for fail operational/fail safe operation is obtained through multiple latches; i.e., adequate load capability exists if any two latches fail to carry load.

g. High reliability of operation is obtained by using electrically redundant motor configurations in each latch actuator.

h. In event of mechanical jamming that prevents unlatching by the electric motor, the motor support arrangement allows manual unlatch by removing a screw accessible from the exterior of the deployment adapter. Removal of the same screw allows latch overtravel to get the separation cam out of the way for remate and landing in event of actuator failure during retrieval.

4.3.1.5 Docking Alignment Guides. The Tug is reinserted in the deployment adapter by using the RMS, which has a position accuracy of approximately ±3 inches (7.5 cm). Since terminal positioning of ±0.19 inch (0.5 cm) is needed for shear pin engagement, alignment guides must be provided. The guides also give protection from accidental interference of equipment during deployment. A staged or progressive alignment guide is suggested (see Figure 4.3-14).

The Tug umbilical panel supports and the docking aid supports enter the deployment adapter 60 and 30 inches (150 and 75 cm) respectively before docking and are located

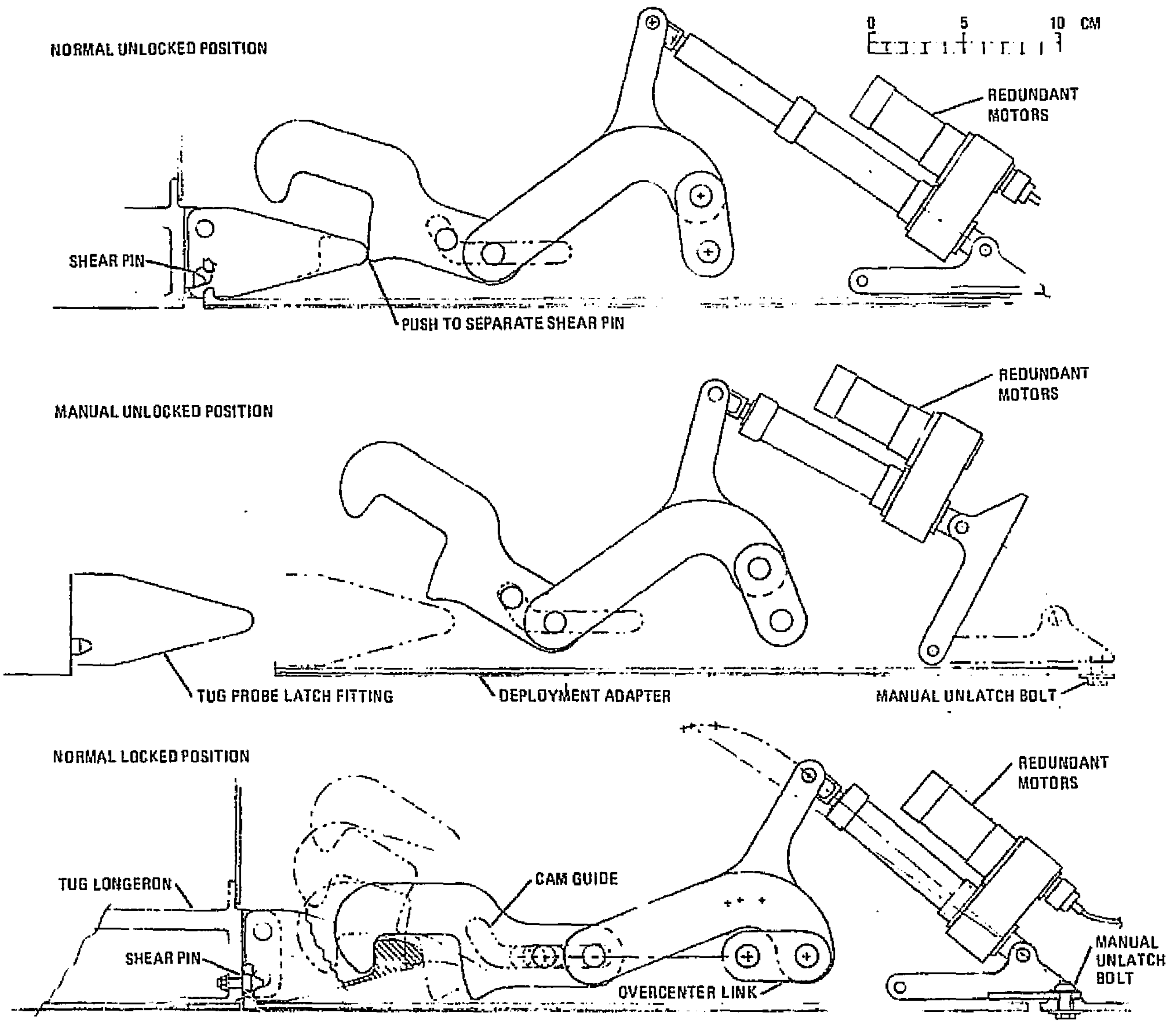

Figure 4.3-14. Tug Adapter Latch

to enter with up to 6 inches (15 cm) radial misalignment. The positions of the supports cause the Tug to align within ±0.8 inch (2.0 cm).

The probe and guide portion of the Tug-adapter latch engage at 3 inches (7.5 cm) from docking and effect alignment to less than ±0.19 inch (0.5 cm) error.

The tapered end of the shear pins engage and, provided with the latch pull-up force, effect final Tug to adapter alignment.

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4.3.2 REMOTE MANIPULATOR SYSTEM. The remote manipulator system (RMS) is a standard Orbiter supplied equipment to perform functions of payload deployment, retrieval docking, inspection and EVA support. The purpose of this phase of the interface study was to evaluate the adequacy of the RMS in accomplishing the assigned tasks, to identify Tug and peripheral equipment configurations to complement RMS use, and to recommend additions or clarification of RMS operational characteristics.

The preliminary description of the RMS given in JSC 07700, Vol XIV covered geometric operation but omitted the control system operation necessary for functional evaluation. The required control system operation was identified and submitted as a proposed Orbiter interface change to NASA MSFC for inclusion in the JSC payloads accommodation document. The configuration of the RMS used in the study is shown in Figure 4.3-15. The torque values were assumed to act around each joint hinge axis. Moments acting around the other two axes perpendicular to the hinge axis were not evaluated but must be considered by the RMS contractor (not selected at present) in the hardware design and development.

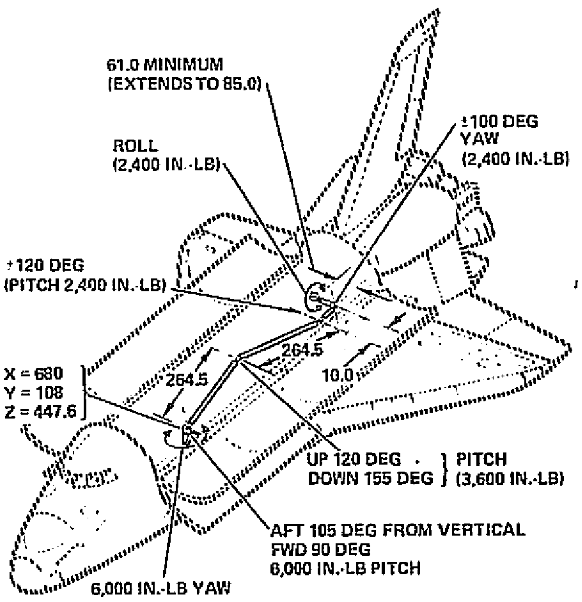


Figure 4.3-15. Remote Manipulation System

RMS applicability for Tug involves its use during deployment, retrieval, and as backup to Tug and deployment adapter mechanisms. Considerations for its use include attachment provisions and force capability, motion description, clearances needed for operation, elapsed time for operation, and its compatibility with Tug/Orbiter separation and deployment methods.

4.3.2.1 RMS Operational Description. Use of the RMS for deployment and retrieval of the Tug is accomplished through a coordinated effort of preprogrammed computer control with manual trim and override by the Orbiter pilot, who mans the payload handlers station.

For deployment, initial RMS/Tug engagement is performed with the Tug in the 35 degree (0.61 radian) rotated position. An Orbiter crew initiated preloaded computer program positions the RMS so that its end effector is aligned approximately 3 feet (90 cm) away from the Tug socket. The RMS wrist mounted TV camera gives visual verification of proper alignment (Figure 4.3-16). If a lateral or rotational position error exists, a manual adjustment control is used for nulling. The computer program is

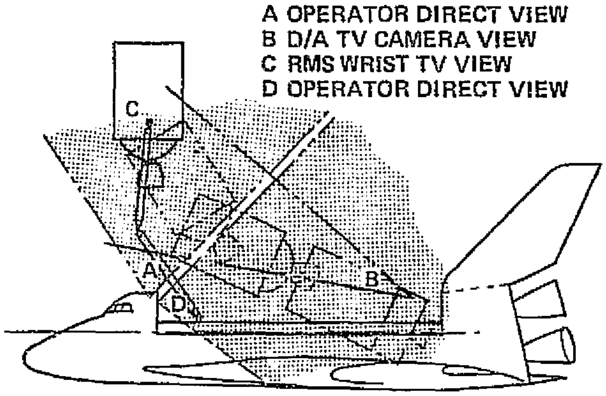


Figure 4.3-16. Visual Monitoring

continued, with manual jog override, until RMS attachment is accomplished. Tug removal from the deployment adapter is similarly performed. A preloaded computer program with manual adjustment control capability is used, with a D/A located TV camera used for crew visual monitoring. Once the Tug clears the adapter, positioning continues through computer control with direct visual progress assessment by Orbiter crew members.

Retrieval of the Tug involves more complexity than deployment in that the RMS must be attached to the free flying Tug. The retrieval procedure is accomplished with the Tug safed, oriented and placed in an attitude hold condition before approaching the Orbiter. Its pre-attachment position is approximated by the orientation shown in Figure 4.3-16. Visual verification of Tug position through two views; i.e., direct vision and a TV monitor (Figure 4.3-17) provides assurance of Tug to Orbiter distance necessary for collision avoidance. For RMS alignment, a visual target painted on the Tug (view C) and oriented to crosshairs on the TV monitor aids the attachment operation. With the Tug and Orbiter positioned and stabilized, the RMS is aligned to the attachment fitting using the RMS mounted TV as primary aid. Immediately before active attachment, both the Tug and Orbiter attitude control systems are turned off so that no acceleration exists between the RMS and fitting. The RMS control capability enables end effector velocity matching to the Tug, which is easily accomplished with man-in-the-loop computer control. Attachment is obtained by extending the end effector until a switch signals contact to cause grasping of the Tug. The Orbiter attitude control is reactivated and the Tug ACS is safed for mission termination.

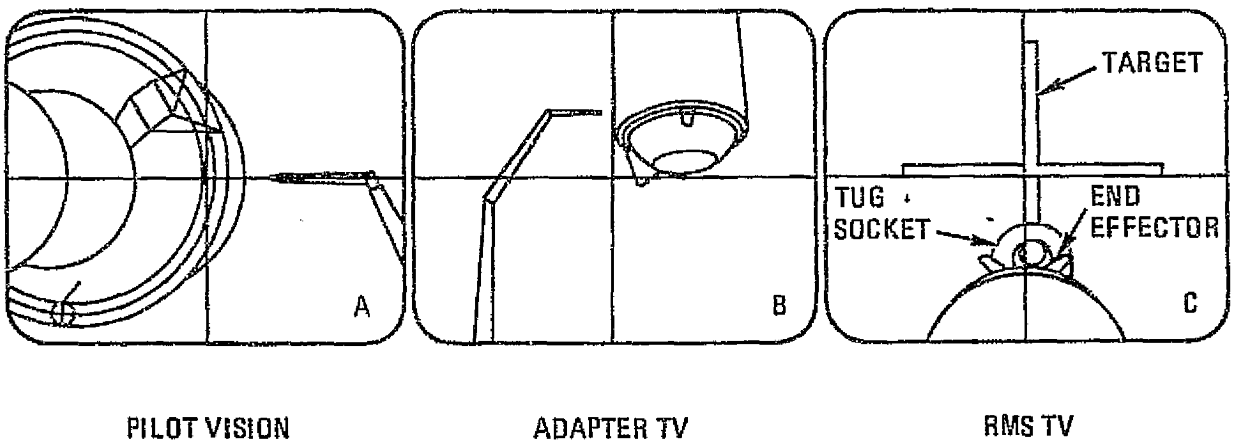


Figure 4.3-17. Preattachment Viewing

For translating the Tug and insertion into the deployment adapter, direct vision through the bulkhead window and TV vision from the deployment adapter camera are used to ensure proper alignment. A target located on the rear of the Tug is positioned so that it directly approaches the deployment adapter camera. This provides an accurate vertical and lateral position monitoring view for the pilot. The 6-inch-diameter (15 cm) target is shown in Figure 4.3-18 as it would be seen by the pilot on the TV monitor when properly aligned at two distances from docking. Manual trim input to

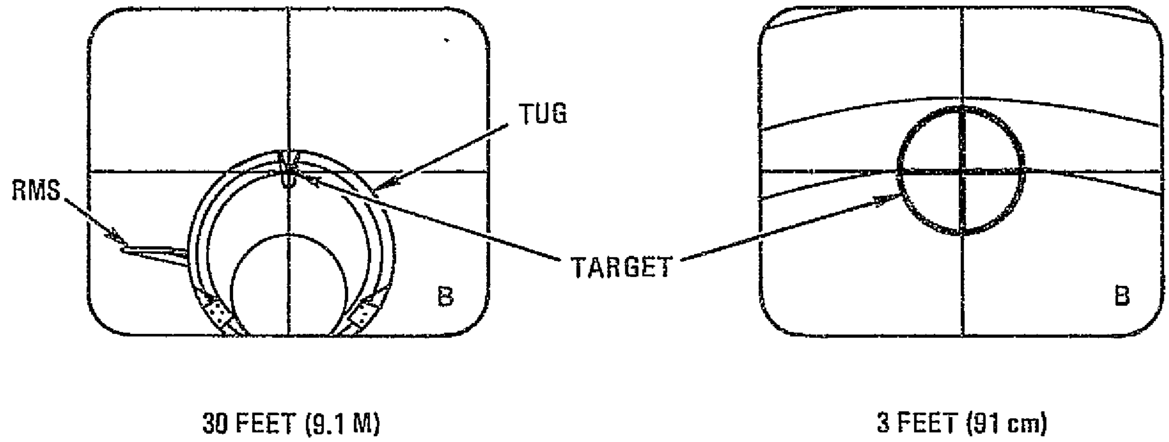


Figure 4.3-18. Tug Docking Target

the computer-controlled docking program using visual docking target assessment allows correction of position errors in the vertical Z and lateral Y direction at the target. The significant position error remaining is roll about the Tug center axis.

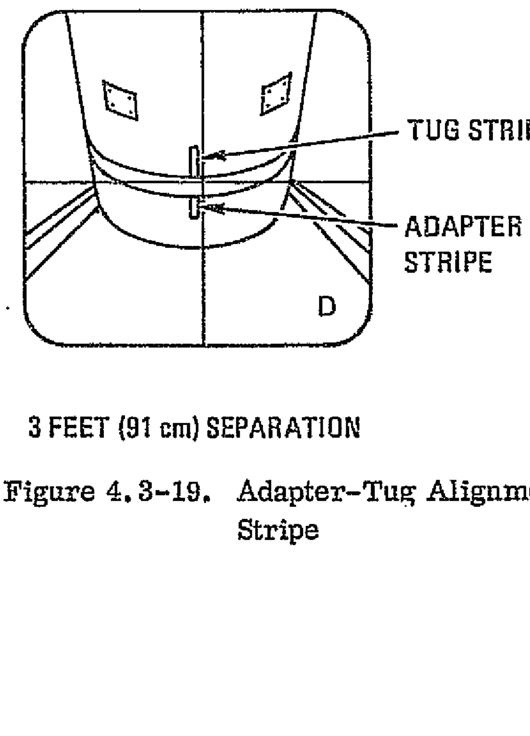


Figure 4.3-19. Adapter-Tug Alignment Stripe

To assist the pilot in observing and correcting roll error, a stripe is affixed to the Tug and adapter lower centerlines, Figure 4.3-19, which can be seen through the Station 582 bulkhead window. Terminal alignment is obtained through the mechanical docking guide system described in Section 4.3.1.5. Following insertion, the adapter latches are actuated to complete retrieval, the RMS is detached, the Tug is rotated into the cargo bay, and the Orbiter mission progresses to the next phase.

4.3.2.2 RMS Control Techniques and Timelines. Use of the RMS to deploy and retrieve Tug requires a total system study to ensure interface compatibility. Involved are the Tug and spacecraft, deployment adapter, end effector and receptacle, RMS geometry, rate and force characteristics, manual and computer control, TV and direct vision capability, alignment guides, sensors and aids, and the flight crew. Retrieval is considered the most difficult operation; specifically attaching the RMS to Tug and repositioning and inserting the Tug into the deployment adapter. Deploying involves the same activity but with much less emphasis needed for guiding and alignment since the Tug will be moving in a direction away from the Orbiter. The required forces are greater for deployment, however, owing to the larger mass of full propellant tanks. Where equipment function and design detail were lacking, assumptions were made to allow development of retrieval operations. The basic RMS information has been recommended through submittal of a proposed accommodations change to MSFC. Since the design of the RMS system was not a part of this study, the effort was limited to defining a singular method of its use by the Tug, and evaluating the RMS performance required.

RMS attachment at the Tug center of gravity is desirable; however, due to the varying payload size, weight, and length and Tug propellant loading, a broad range of cg positions exists. A chart showing cg station for each Tug plus payload combination plotted versus combined weight, Figure 4.3-20, indicates the large excursion obtained. To minimize moments due to CG offset, the RMS attachment should be located near the center station of the "with propellant" curve, or approximately Station 1100. The RMS performance calculations were done using a CG Station 1087 and an RMS attachment Station 1140, to observe the effect of a large offset. Detail analysis of the RMS function will require calculations using each configuration weight, inertia and cg to guarantee performance margins.

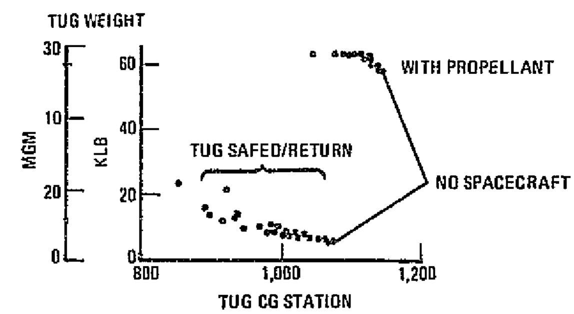


Figure 4.3-20. Tug and Payload CG

To translate Tug from the adapter to a position above the pilot's station, the RMS can be articulated in one of two ways. Performance limitations exist for both. An operational difficulty exists when the RMS wrist joint is physically located nearly in line with the shoulder centerline. Figure 4.3-21 illustrates the two motions. As the end of the RMS is moved from position (A) to (B) the motions are identical. At (B), the wrist is on the shoulder centerline, and progress toward (C) can be accomplished by holding the shoulder fixed and continuing the travel with each joint as in (1), or the shoulder can be rotated through 180 degrees (π radians) before continuing the travel, as in (2). For the motion described in (1), the wrist must cross precisely through the shoulder centerline. For the motion in (2), it is preferred that the wrist not intersect the

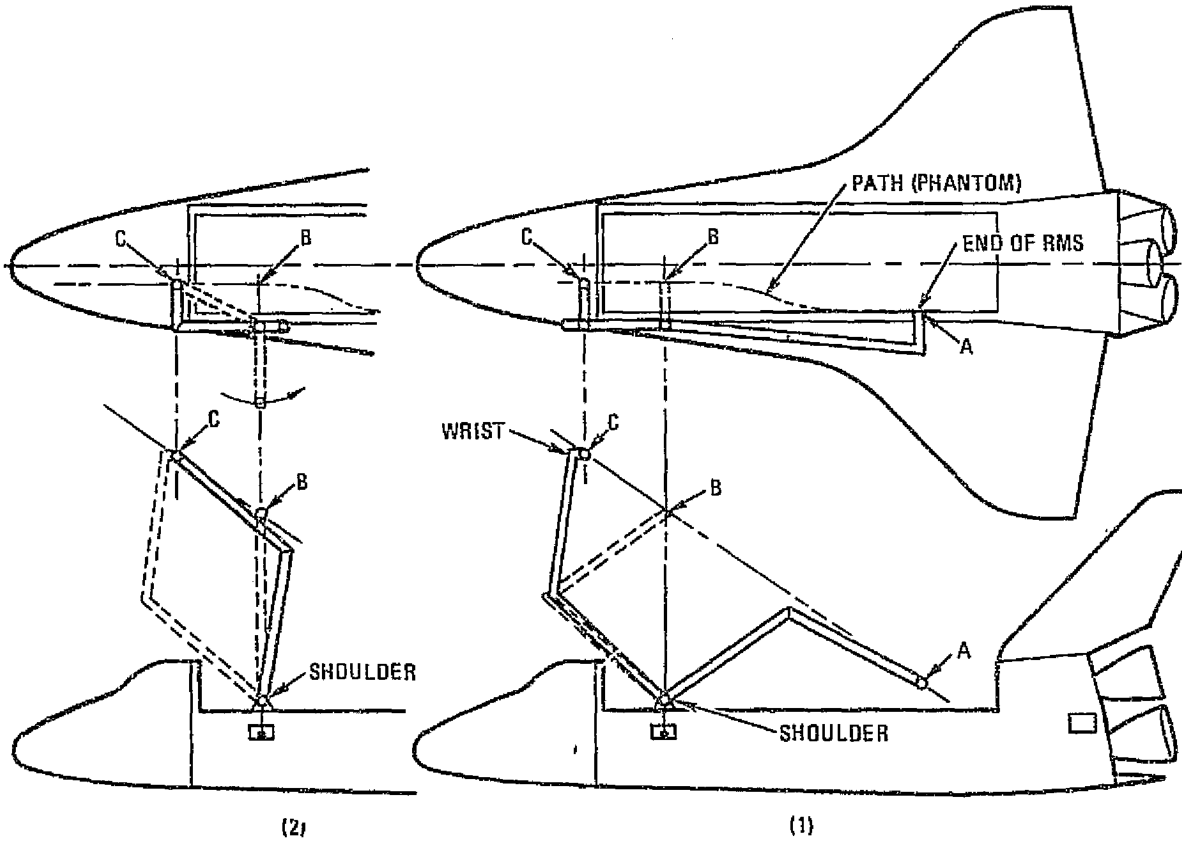
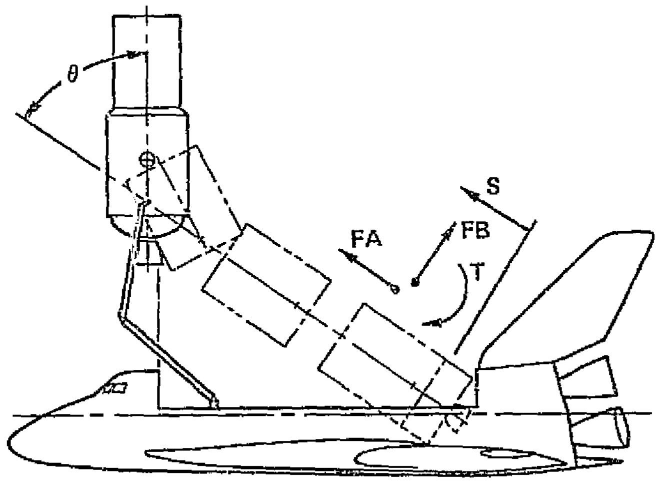


Figure 4.3-21. RMS Motion

shoulder centerline, because if it does, axial travel at the end of RMS must be stopped while the shoulder is pivoted through the half revolution. Over the shoulder articulation (1) was chosen for use in deploying the Tug since a smooth time-distance function could be used, thus avoiding extremely high rate RMS operation. Addition of an additional hinge at the shoulder would eliminate the disadvantage of (1).

Evaluation of the RMS function was performed for a maximum weight Tug and payload with a forward combined cg, using the center of the deployment adapter as the geometric axis. The assumed configuration and axes definition are shown in Figure 4.3-22 with the adapter rotated to 35 degrees (0.61 radian). The side motion indicated is required to cause the wrist to travel over the shoulder centerline. The pitch-up angular motion, Θ, is the result of payload contamination studies presented in Section 4.5.

Following release of the Tug-adapter latches, the Tug is deployed by the RMS through computer control to preprogrammed position versus time function, Figure 4.3-23, called for by the pilot. The motion is characterized by a linear axial acceleration out of the adapter, with Tug maintained on centerline until the engine nozzle clears the adapter station at a distance of approximately 10 feet (3 meters). Linear travel is



CONFIGURATION	
WEIGHT	60,000 POUNDS (27,270 kg)
CG STATION	1087
RMS STATION	1140
AXIAL MOTION, S	60 FEET (18.3 m)
ANGULAR MOTION, θ	55 DEGREES (0.96 RAD)
SIDE MOTION, C	44 INCHES (1.1m)
PITCH INERTIA,	3.97×10^6 LB-SEC^2-IN.

Figure 4.3-22. Deploy Configuration

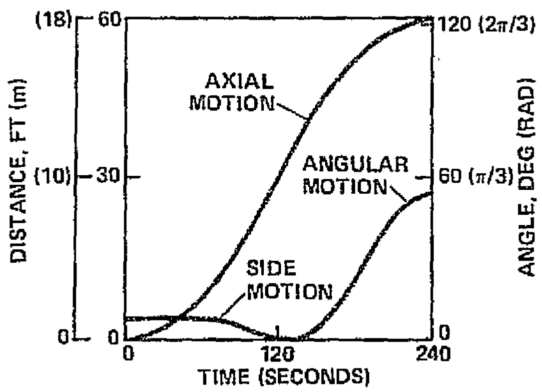


Figure 4.3-23. Motion Definition

continued to deployment midpoint (120 seconds), at which time a linear axial deceleration commences to arrest motion. The 44 inch (1.1 meter) side motion is a linear acceleration/deceleration occurring between times of 60 and 130 seconds. The angular motion is a sinusoidally varying acceleration beginning at 120 seconds and completed at 240 seconds. The equations of motion used are:

Constant acceleration:	$S = S_o + K_5 t^2$	$0 < t < t_a$
Deceleration:	$S = S_{max} - K_6 (t_{max} - t)^2$	$t_a < t < t_{max}$
Sinusoidal:	$\theta = \theta_o + K_3 (\cos K_4 t - 1)$	$t_o < t < t_{max}$

The constants in the equations are obtained as follows:

$K_3 = -1/2 \times$ angle traveled

$K_4 = \pi / t_{max}$

K_5 = Distance traveled during acceleration/t_a^2

K_6 = Distance traveled during deceleration/$(t_{max}-t_a)^2$

t_a = Time for linear acceleration

As the Tug is being deployed, especially while still in the adapter, the pilot will be closely monitoring the position and direction of travel, and through the use of the RMS hand controller, will adjust and correct the RMS deploy functions. Selection of the specific motion equations is somewhat arbitrary, since the time-distance curves for constant/sinusoidal input forces nearly coincide, as shown in Figure 4.3-24, with the initial travel being slower with constant acceleration providing more time and force available for manual trim/override. A sinusoidal pitch motion was selected to reduce the peak RMS joint torques, which result from a summation of the pitch and axial motion forces.

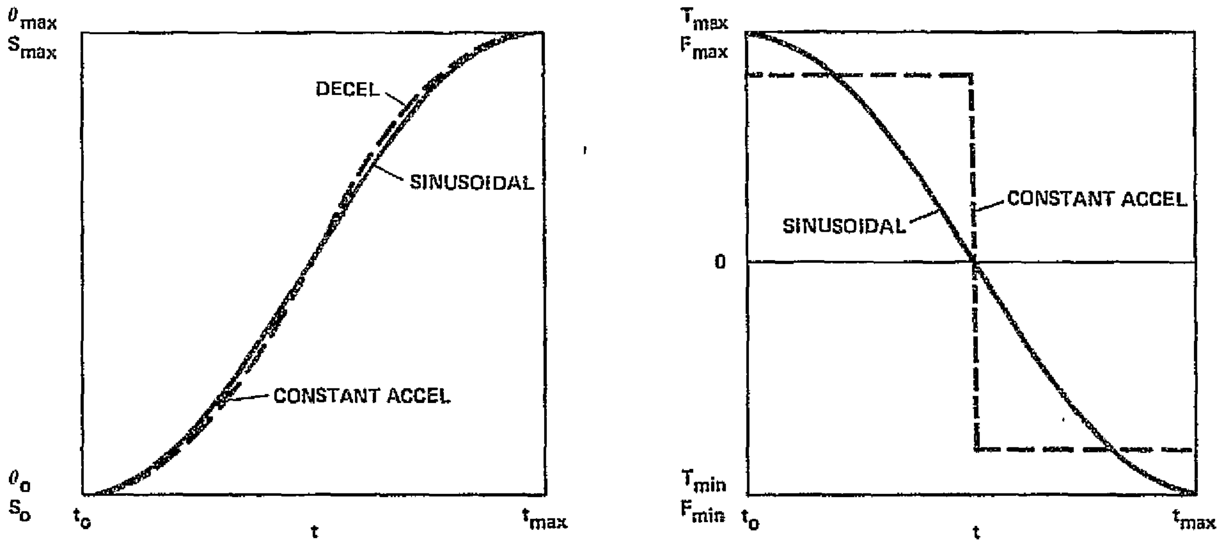


Figure 4.3-24. Time-Motion Comparison

Using the defined time-motion functions, the RMS joint requirements were computed and results plotted using an HP-9810A calculator. The RMS configuration and joint identification used, Figure 4.3-25, and the JSC 07700 characteristics are:

Identification	Name	Motion	Max. Torque, in-lb (N.m.)
P	Wrist	Roll	2400 (271.2)
A	Wrist	Yaw	2400 (271.2)
B	Wrist	Pitch	2400 (271.2)
C	Elbow	Pitch	3600 (406.7)
D	Shoulder	Pitch	6000 (677.9)
E	Shoulder	Yaw	6000 (677.9)

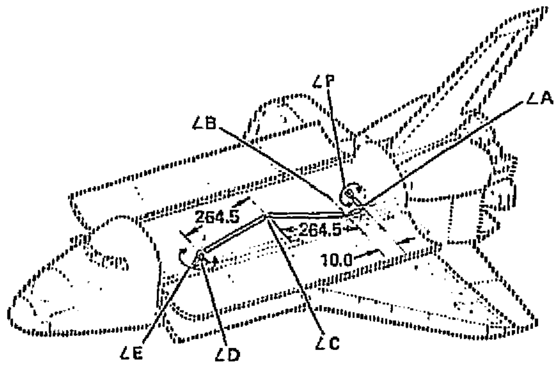


Figure 4.3-25. RMS Joint Identification

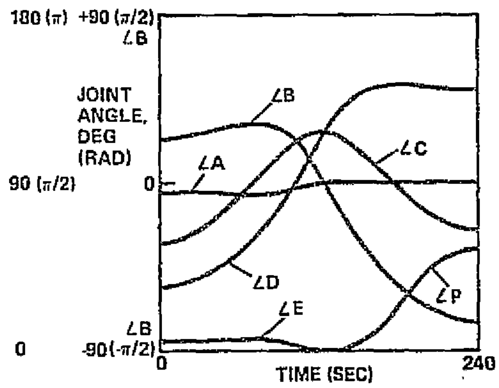


Figure 4.3-26. RMS Joint Angle vs Time

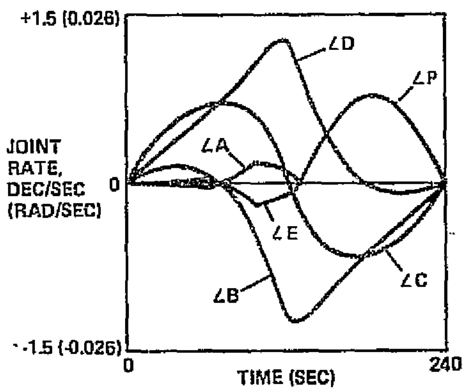


Figure 4.3-27. RMS Joint Rate vs Time

Angles were computed and plotted for each RMS joint with the wrist extension length held constant and parallel to the Y-Y axis of the Orbiter, the wrist segment between joints A and B held parallel to the X-Y plane, and "over-the-shoulder" motion assumed. Discrete angles were thus obtained. Figure 4.3-26, for each specific time.

Joint angular rates ($\dot{\Theta}$) were obtained by computing and plotting $\Delta\Theta/\Delta t$ for each joint, Figure 4.3-27.

Using the geometry and inertial data, Figure 4.3-22, the torque and forces acting on the Tug cg necessary to produce the desired motion were computed, Figure 4.3-28, assuming a rigid, infinite mass Orbiter. With the Orbiter mass equal to about three times the Tug mass, the forces thus calculated will be greater by the ratio of 4:3 than actually needed to produce the defined relative motion. This tends to be conservative in that increased force is available for contingency operation. The joint torques obtained are within the RMS capability available as specified in JSC 07700 Vol XIV Rev C.

Combining the torque, 2150 in-lb (240 N.m), and maximum rate, 1.27 deg/sec (0.022 rad/sec) of joint "D" at 120 seconds, a required power was computed:

$$HP = 2\pi T N/550$$

$$= 2\pi \times \frac{2150}{12} \times \frac{1.27}{360}/550$$

$$= 0.007 \text{ horsepower (5 watts)}$$

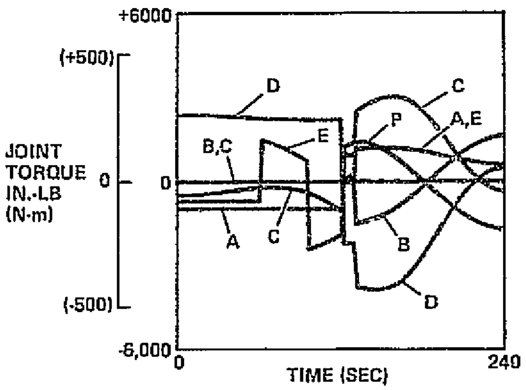


Figure 4.3-28. RMS Joint Torque vs Time

The individual preliminary joint characteristics, given in document JSC-08997 dated 22 August 1974 and reproduced in Table 4.3-4, do not define the available power; however, the rate and torque required are both less than the maximum listed. Using the 772 ft-lb stall torque and the loaded rate of 0.229 deg/sec, a power of 0.0056 horsepower (4.2 watts) is obtained, which is in the same magnitude as that required and is probably acceptable in lieu of the conservative force calculations.

Table 4.3-4. RMS Joint Capability (Ref Page 6, JSC 08997)

Parameter	Shoulder Yaw	Shoulder Pitch	Elbow Pitch	Wrist Pitch	Wrist Yaw	Wrist Roll
Torque, Stall, ft-lb	772	772	502	231	213	200
Joint Rate Loaded, rad/sec (deg/sec)	0.004 (0.229)	0.004 (0.229)	0.0057 (0.327)	0.0083 (0.476)	0.0084 (0.481)	0.0105 (0.602)
Joint Rate Unloaded, rad/sec (deg/sec)	0.0537 (3.077)	0.0537 (3.077)	0.0768 (4.400)	0.1107 (6.343)	0.1130 (6.474)	0.0847 (4.853)

A more detailed study of the RMS system can also reduce the power and rates by more sophisticated implementation methods, and by tailoring the time-motion equations. Some changes that would result in decreasing the required power of joint D are:

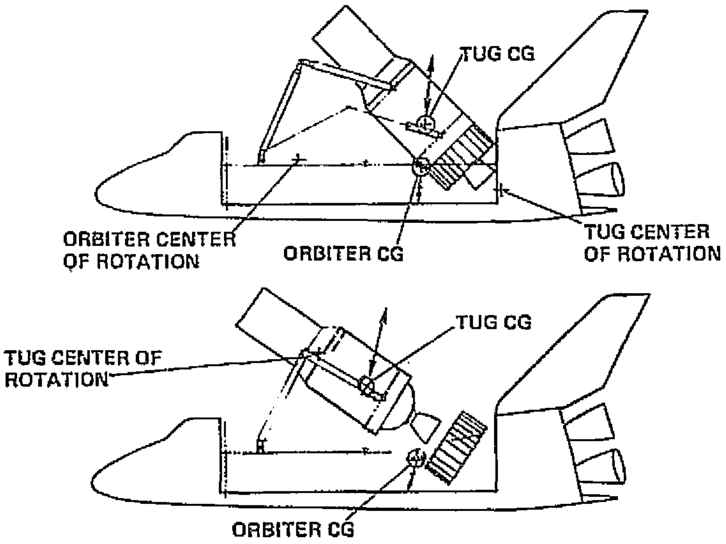
a. Use sinusoidal acceleration for axial motion.

b. Increase the total deployment time.

c. Use hybrid time-motion equations.

Control of the Tug while attached through the manipulator to the Orbiter depends on the characteristics of the RMS and the individual masses of the two vehicles. To prevent damage to the relatively flexible RMS when Tug connected, it is necessary to prevent or damp resonant motion between the vehicles. Damping can be accomplished through the normal control system if the control response is sufficiently faster (3 or 4 times minimum) than the RMS connected natural frequency.

A simplified model of the Orbiter, Tug, and RMS was used in the NASTRAN computer program to develop an approximate natural frequency. The predominant first mode frequency produces a period of about twenty seconds, Figure 4.3-29, which can be detected visually and provides adequate time for reaction through the man-machine interface. The directions of relative motion are indicated in the figure. A more precise modeling is recommended to account for the full six degrees of freedom system using improved estimates of RMS arm stiffness and including torsional characteristics. It is assumed that a more rigorous analysis will produce a lower first mode frequency due to decreased system spring constant, making this preliminary analysis conservative.



TUG NEAR ADAPTER

MODE	FREQ	PERIOD
1	0.0508 Hz	19.7 SEC
2	0.171 Hz	–
3	0.471 Hz	–

TUG 3.7 METERS FROM ADAPTER

MODE	FREQ	PERIOD
1	0.0581 Hz	17.2 SEC
2	0.177 Hz	–
3	0.405 Hz	–

Figure 4.3-29. Tug-RMS-Orbiter Natural Frequency

Analysis of the remote manipulator system kinematics is a complex task requiring full knowledge of its characteristics. Within the limitations posed by the sparse and preliminary data available, it has been shown that the RMS will be capable of deploying the Space Tug and payload. With the added capability of RMS tip velocity control requested through an accommodations change, Tug retrieval and docking is the reverse of deployment and can also be successfully accomplished.

The combined remote manipulator system requirements identified for Tug operational use are summarized in Figure 4.3-30. The interaction of computer control, manned supervision/adjustment, and the mechanical system is depicted schematically.

4.3.2.3 <u>RMS End Effector Requirements</u>. Full use of the RMS to accomplish the assigned tasks of payload deployment, handling and retrieval; docking payloads to the

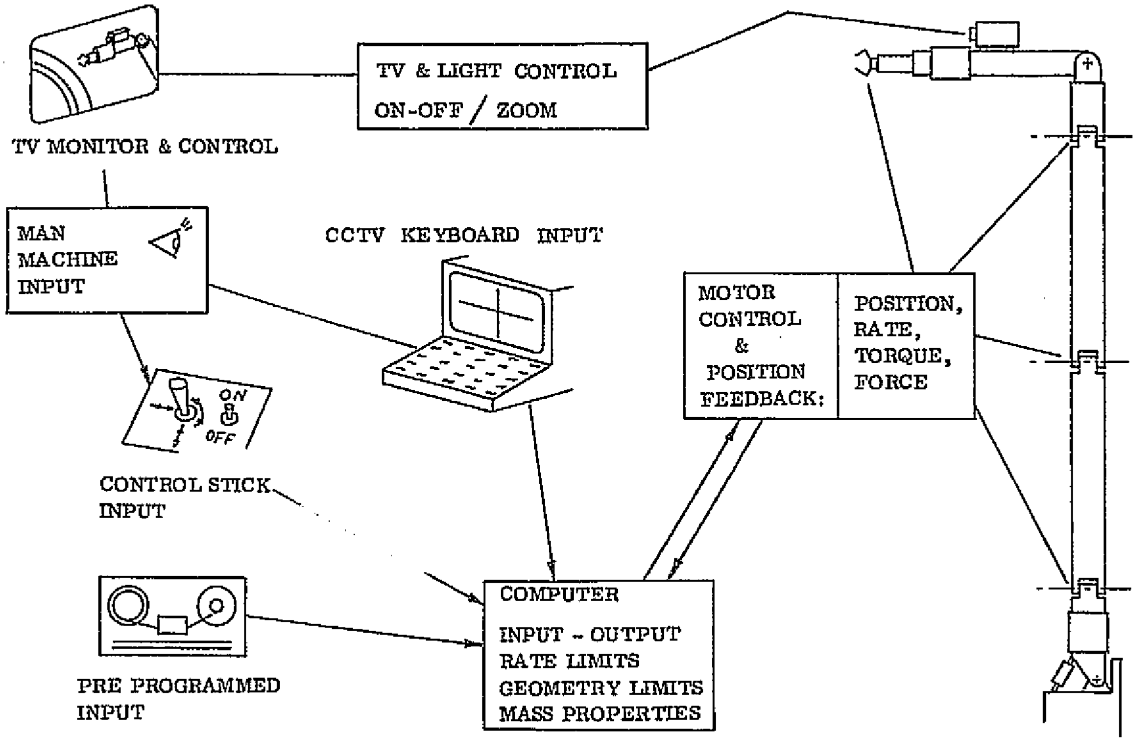
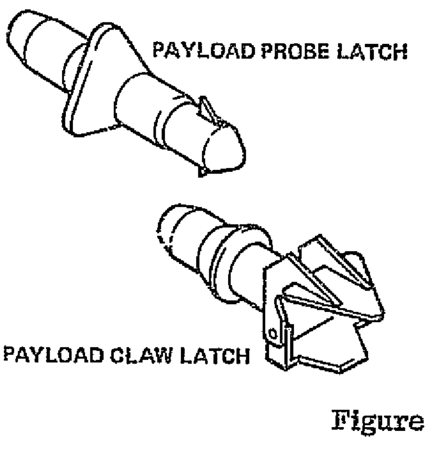


Figure 4.3-30. Remote Manipulator System Interface

Orbiter and other stabilized elements; inspection; and EVA support requires diverse capability in the end effector design. Deploying and retrieving a Tug requires an end effector attachment capable of transmitting loads and motions in six degrees of freedom with minimum free play at the attachment interface while also being able to remotely connect with up to 10 degrees (0.17 radian) angular misalignment and also to disconnect with a minimum disturbing force. Either a probe or claw type end effector, Figure 4.3-31, appears to meet the requirements for Tug deployment and retrieval.



REQUIREMENTS

- TRANSMIT LOADS
- RELEASE TUG WITH MINIMUM OR REPEATABLE DISTURBANCE
- ATTACH TO TUG WITH MINIMUM DISTURBING FORCE
- ATTACH TO TUG WITH SIGNIFICANT INITIAL ANGULAR & LINEAR MISALIGNMENT

Figure 4.3-31. Tug-RMS End Effector

An end effector-mounted proximity switch has been proposed by the interface study via a proposed accommodations change to satisfy the minimum attachment disturbing force requirement. See change 005, Section 5.2, Volume III.

4.3.3 MECHANISM BACKUP CAPABILITY. Additional tasks assigned to the RMS include payload servicing, inspection, and EVA support. These tasks imply a dexterity not available with a probe/drogue end effector. Backup tasks may occur due to the unscheduled activity associated with disconnecting a failed pivot actuator or checking alignment/engagement of umbilical panels upon loss of position indication.

Both example tasks require an end effector capable of operating perpendicular to the Orbiter centerline and aft of Station 1246. The present RMS reach with its end effector similarly oriented is Station 1219. An extension end effector and/or a movable tip end, Figure 4.3-32, appears necessary as does on-orbit exchange with the probe type end effector.

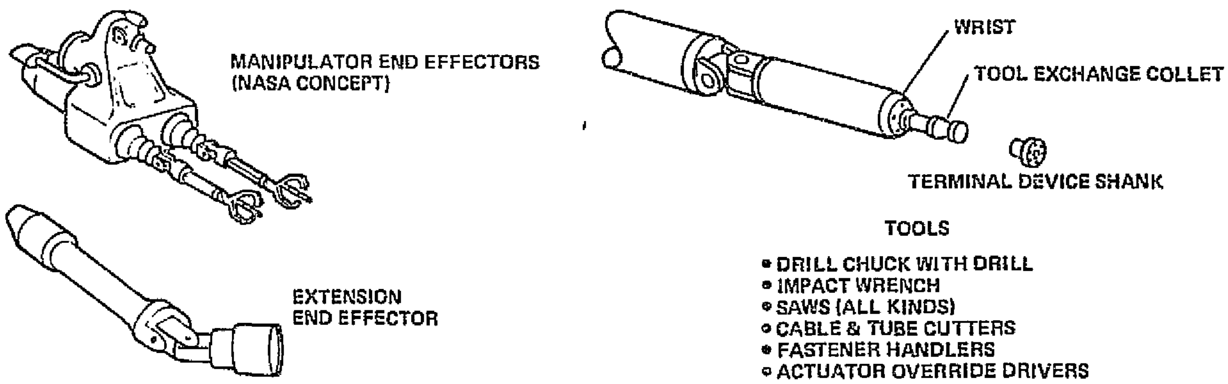


Figure 4.3-32. Exchangable End Effectors

4.4 FLUID SUPPORT SYSTEM INTERFACES

The design of the Tug and associated deployment adapter-mounted and Orbiter-provided fluid service equipment must be compatible with all Orbiter operations for both normal and aborted missions. All Tug fluids with the exception of APS monopropellant are loaded on-pad after payload bay door closure. Thus service lines with Orbiter interfaces for loading, unloading, venting, and relieving are required. All Tug service lines that require connection to ground pass through panels provided on the Orbiter aft payload bay bulkhead (1307 panels) through the Orbiter aft fuselage to separate fuel and oxidizer disconnect panels on opposite side of the aft fuselage (Figure 4.4-1). These remain connected until launch and are called the T-0 (time zero) panels. This section summaries requirements for fluid service equipment, presents trade studies supporting fluid service equipment and associated interface definition, and defines final baseline requirements at the Tug/Orbiter interface.

4.4.1 SYSTEM REQUIREMENTS. Tug and Orbiter system requirements that establish fluid service equipment requirements are identified in this section.

4.4.1.1 Normal Operation. Fluid system requirements for normal operation are summarized in Table 4.4-1. Auxiliary Propulsion System (APS) propellants are loaded in the payload changeout room before Tug insertion into the Orbiter, therefore

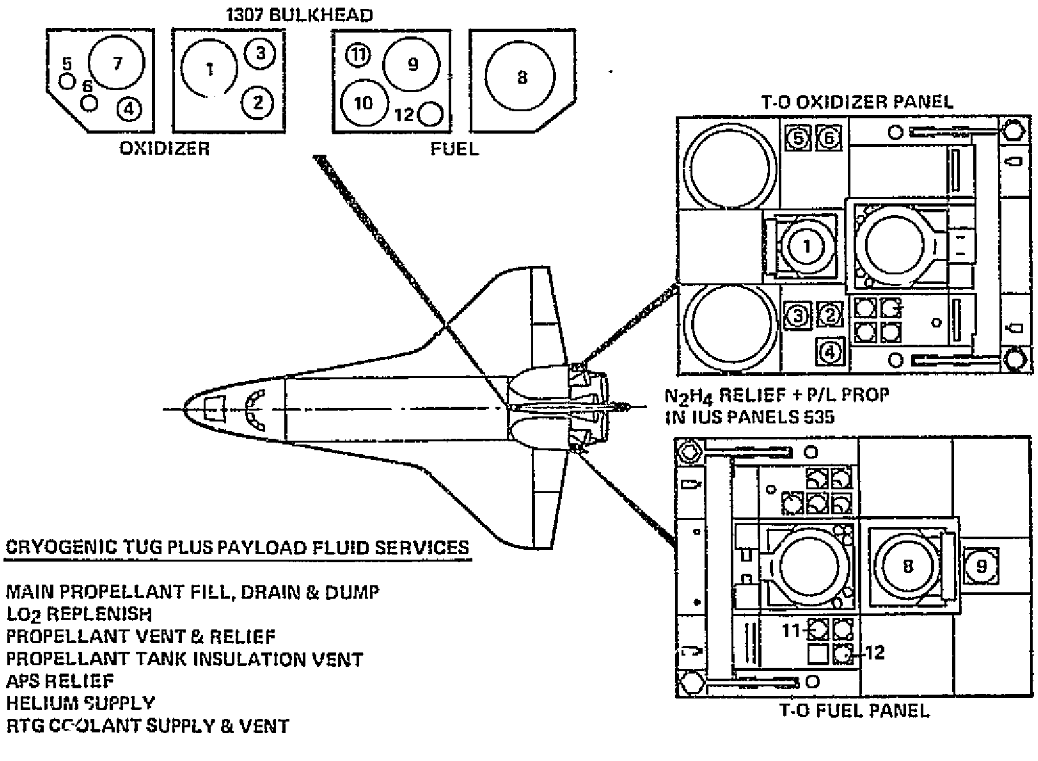


Figure 4.4-1. Fluid Interface

Table 4.4-1. Tug Fluid Systems Requirements for Normal Operations

Main Propellants	LO_2	LH_2
Max Quantity, lb (kg)	44080 (19994)	7460 (3384)
Loading Time, min	30	30
Unloading Time, min	30	30
Loading Flowrate, lb/sec (kg/sec)	24.5 (11.1)	4.144 (1.88)
Unloading Flowrate, lb/sec (kg/sec)	24.5 (11.1)	4.144 (1.88)
Venting Rate, lb/sec (kg/sec)		
Prelaunch		
Max steady state	0.195 (0.0885)	0.25 (0.113)
Min steady state	0.15 (0.068)	0.20 (0.091)
Flight		0.144 (0.065)
Topping Rate, lb/sec (kg/sec)		
Min steady state	0.15 (0.068)	0.20 (0.091)
Max steady state	0.195 (0.0885)	0.25 (0.113)
Level adjust	2.0 (0.91)	2.0 (0.91)
Pressures, psia (N/cm^2)		
Loading	(Note 1)	(Note 1)
Unloading	>15.5 (10.67)	>15.5 (10.67)
Topping	(Note 1)	(Note 1)
Propellant Saturation	15.5 (10.67)	15.5 (10.67)
Leakage/Purge Vent, lb/min (kg/min)		
Pretanking (5 minutes only)	0.06 (0.027)	0.5 (0.227)
Loading	0.001 (0.00045)	0.01 (0.0045)
Ascent	0.03 (0.0136)	0.25 (0.113)
Auxiliary Propulsion System		
Loading/Unloading	(Off-pad)	
Relief Rate, lb/sec (kg/sec)	0.05 (0.023)	

(1) Minimum practical to minimize propellant saturation pressure.

Table 4.4-1. Tug Fluid Systems Requirements for Normal Operations, Contd

Main Propellants	LO_2	LH_2
Helium System	Vehicle	Adapter
Quantity, lb (kg)	20.0 (9.07)	60.3 (27.35)
Charge Time, hr	1.0 total Vehicle & Adapter	
Max pressure, psia (N/cm^2)	3200 (2200)	3200 (2200)

the APS has a relief requirement only. All other fluids are loaded on-pad during the launch preparations. A one-hour charge time is assumed for the helium systems. This system may be charged at any time compatible with Orbiter operations.

Main propellant loading is assumed to be concurrent with Orbiter main propellant loading, which is as follows:

	Operation	Time Required (minutes)
	Facility chill	7
	Orbiter Childown	20
	Fill to 2 percent	14
Orbiter →	Fill to 98 percent	30
Crew Ingress	Fill to 100 percent	19

The fill time of 30 minutes from 2 to 98 percent establishes the flowrate requirement for the fill system. After loading, propellants are maintained fully loaded until launch by topping at a rate equal to the boiloff rate. The topping rate may be increased if required just before launch for final propellant level adjustment. The vent system vents chill down and boil off gases overboard. It is sized for minimum practicable pressure loss to minimize propellant saturation pressures, which affects tank design pressure. All potential sources of leakage are purged and vented overboard. Major purged areas are the leakage containment membranes around propellant tanks and disconnect panel purge compartments, which are vented continuously, and fill, drain, and topping lines, which are purged 30 seconds before launch. Purge venting requirements summarized in Table 4.4-1 are detailed in Table 4.4-2.

At launch, propellant tanks are locked-up (i.e., vents closed) until an altitude of 90,000 feet (27,432 meters) is reached, after which the tanks are vented back down to saturation pressure as the vehicle accelerates, keeping propellant settled. Between Shuttle engine burnout and Tug deployment, zero-g venting at very low rates is enabled as required by use of a thermodynamic zero-g vent device. During ascent, all

Table 4.4-2. Helium Vented Through T-0 Panels

Mission Phase	Time/Duration	Operation	Helium Vented, lb/min (kg/min) LH2 Panels	LO2 Panels
Pre-Launch	During/After Propellant Loading	Disconnect panel purging	0.01 (0.0045)	0.001 (0.00045)
Prelaunch	30 seconds before launch	Fill, drain, topping line purging	1.5×10^{-4} (0.7×10^{-4})	3.5×10^{-5} (1.6×10^{-5})
Pretanking	5 minutes before tanking	Leakage containment membrane purging/drying	0.5 (0.227)	0.06 (0.027)
Launch Ascent	T-0 to T +120 sec	Leakage containment membrane vent-down	0.25 (0.113)	0.03 (0.0136)

Total helium vented — 4.84 lb (2.2 kg)

leakage/purge compartments are vented down to pressures very near ambient (higher only by system ΔP).

4.4.1.2 Shuttle Abort Operation. The Tug must be designed for compatibility with all Shuttle aborts that occur before Tug deployment. For these aborts, methods of safely operating the Tug and subsequently disposing of propellants, either before or after landing must be devised. For the baseline Tug, all of both propellants are dumped before entry. Shuttle aborts may be divided into two categories, characterized by their impact on Tug propellant dumping design requirements:

a. Return-to-Launch-Site (RTLS) Abort. For Shuttle aborts that occur between 125 and 240 seconds after launch, the RTLS mode may be used. In this mode, the Orbiter reverses its direction of flight at high altitude by rotating in pitch to apply retrograde thrust using the main engines. This operation is summarized in Figure 4.4-2. After entering the atmosphere, the Orbiter glides back to the launch site. CG constraints during glide (Figure 4.4-3) dictate a requirement for LO_2 dump before entry. LH_2 dump after entry is prohibited because of possibility of combustion in the Orbiter wake (Ref. 9). Propellants can be dumped during the retrograde thrusting period where ample acceleration for settling is provided (1-3g as shown). Minimum time available is 300 seconds for abort at the last RTLS opportunity. Trajectory data that has significant impact on dumping are shown in Figures 4.4-2 and 4.4-4.

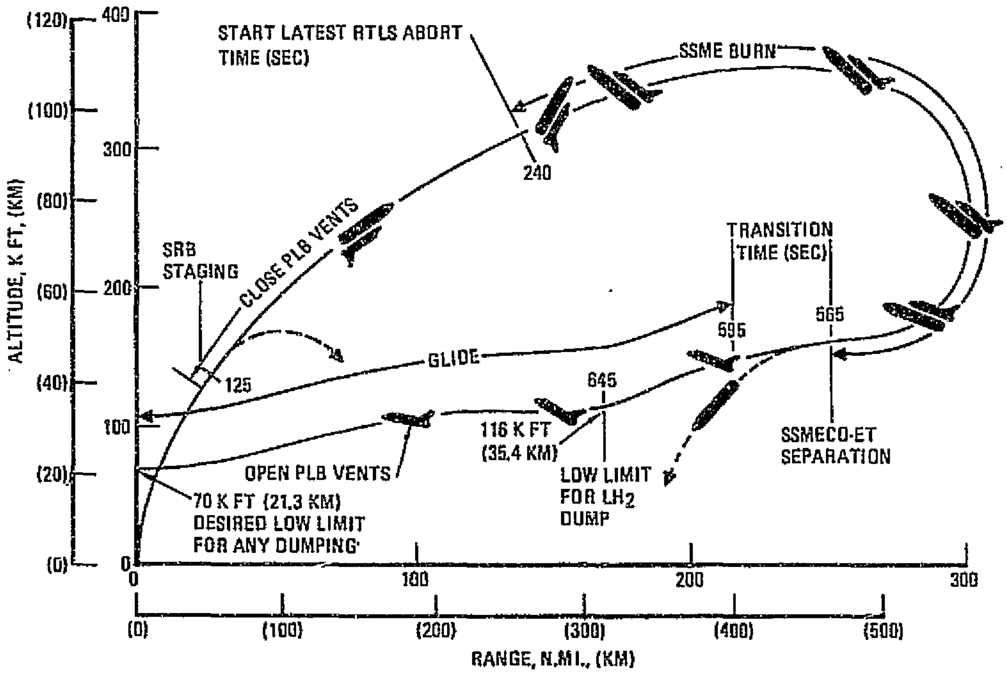


Figure 4.4-2. RTL and Abort Mode

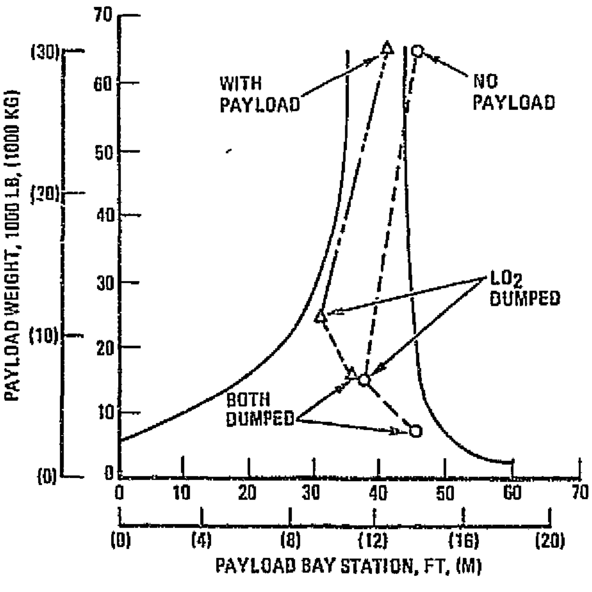


Figure 4.4-3. CG Limits for Atmospheric Glide

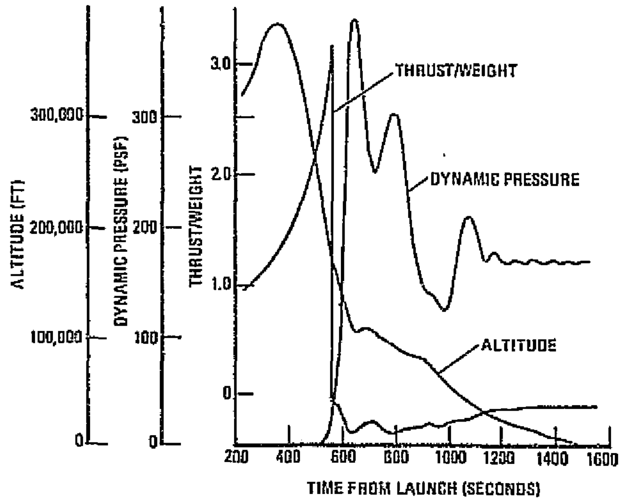


Figure 4.4-4. RTL and Abort Trajectory Data

b. Orbital Abort. After the time limit for RTLS (240 seconds from liftoff), one of three orbital abort modes defined below are used:

1. Abort-Once-Around (AOA) — 220(1) to 400 seconds after launch. The Orbiter continues to slightly less than orbital velocity, retrofires using the OMS, reenters, and lands at the end of the first orbit.

2. Abort-to-Orbit (ATO) — 247 to 306 seconds. The Orbiter proceeds to orbit from which abort is initiated using OMS retro burns.

3. Abort-from-Orbit (AFO) — Anytime after normal orbital injection.

After 240 seconds, time available during SSME operation is shorter than the 300 seconds minimum for RTLS, ranging down to 106 seconds for the last AOA opportunities. Thus designing for dump within the SSME powered time would greatly increase dump system requirements. Both 1) continuing dump through SSME shutdown and external tank (ET) staging, and 2) interrupting dump during ET staging are of questionable acceptability from safety and reliability standpoints. The system must be designed to accommodate AFO, in any case, where no SSME thrusting time is available. Thus a groundrule assumed for this study was that dump would take place after SSME shutdown for all orbital aborts.

Thrust available for orbital abort ranges from zero to a maximum of 12,000 lb (53376N) from OMS plus approximately 5400 lb (24020N) from the RCS (using six thrusters). Time and thrust availability limits are summarized in Table 4.4-3.

Table 4.4-3. Orbital Dump Thrust and Time Availability Limits

Orbiter System Operating	Thrust, lb (N)	Minimum Time, sec	Maximum Time, sec
None	0	3720 (AOA)	over 24,000
OMS	12,000 (53376)	120 (AFO)	440
RCS (4 thrusters)	3,600 (24020)	0	230

(1) For aborts between approximately 220 and 240 seconds after launch, the Orbiter may elect either the RTLS or AOA mode. Dumps for AOA initiated in this period can be made using the RTLS technique if desired.

The minimum OMS/RCS times available assume an abort when only the propellant required for deorbit and reentry control is remaining. The minimum times dictated that the dump system be designed so that part of the Tug propellant is dumped without the use of Orbiter propulsion.

4.4.2 ABORT DUMP DESIGN TRADE STUDIES. Design to accommodate Shuttle abort has a major impact on Tug and tug service line design. This section summarizes the results of trade studies made to aid in selection of optimum subsystem designs and operational modes for compatibility with all Shuttle abort modes.

4.4.2.1 LH_2 Dump Safety. A major abort dump concern was the possibility of combustible H_2/O_2 mixture buildup in Orbiter compartments due to infiltration of dumped propellants. By worst-case analysis, it was found that hazardous mixtures can be avoided for all Shuttle abort modes. There is a general impression that H_2/air mixture between 4 and 95 percent H_2 are combustible and very easy to ignite. This is true at atmospheric pressure but decidedly not true at low pressure. Figure 4.4-5 gives low pressure H_2/O_2 mixture combustibility data used in the analysis. It shows data from Reference 1 on P&W tests on spark igniters for H_2/O_2 thrust chambers and from Reference 2 on Convair tests of ignition limits for the Atlas-Centaur interstage adapter. In both the P&W and Convair tests, the complete boundary of the ignition zone using spark igniter was defined for mixtures of 0 to 100 percent H_2 in O_2 at pressures of 0.1 psia to 1.0 psia (0.069 to 0.69 N/cm^2). Both the Convair and P&W data were taken using continuously sparking igniters operating at 20 hertz, with gap/energy

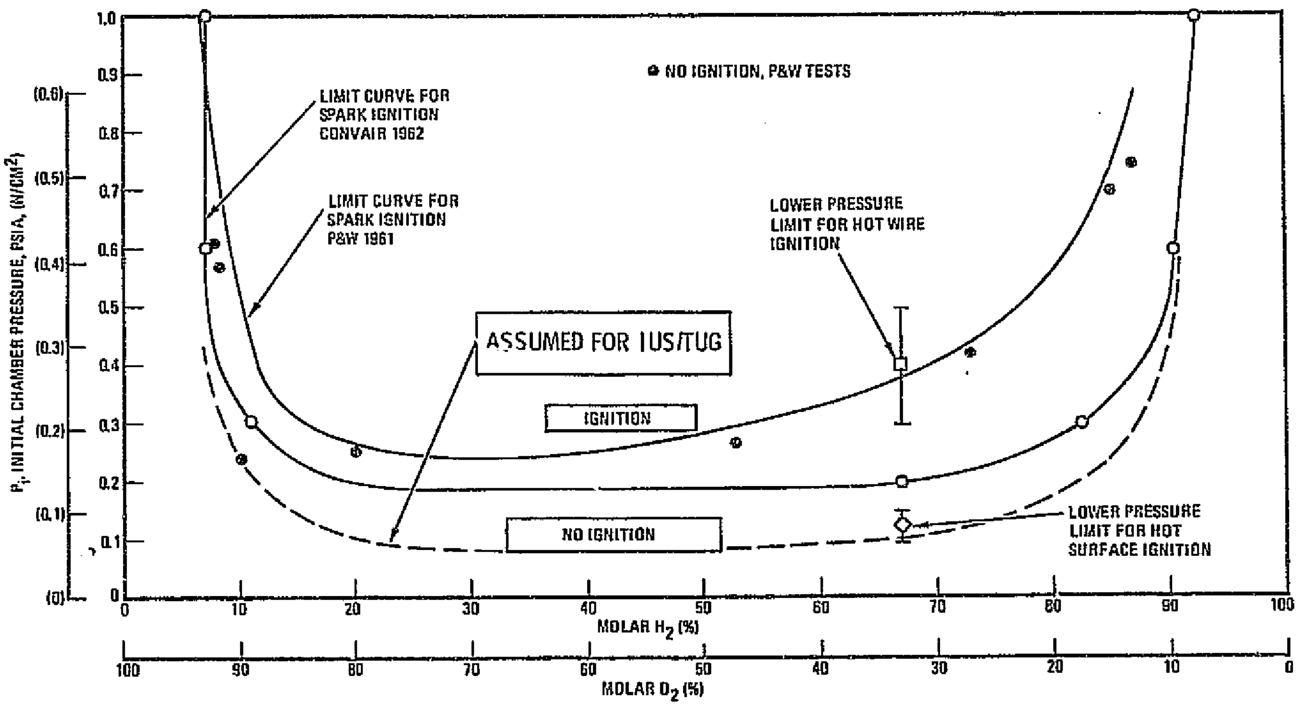


Figure 4.4-5. H_2/O_2 Mixture Ignition Limits

of 1.25 inches (3.17 cm)/8 Joules for Convair and 0.1 inch (0.254 cm)/0.5 Joules for P&W. In addition, the Convair tests included a hot wire and a 22 in.^{2} (142 cm^2) hot surface [up to 2500F (1389K)] ignition sources at 67 percent H_2 by volume, the easiest mixture to ignite. With the hot surface, ignition was obtained at 0.15 psia (0.103 N/cm^2) but not at 0.1 psia (0.69 N/cm^2).

The lowest dotted curve was assumed for the Tug hazard analysis. It parallels the curve developed by Convair for spark ignition, passing through 0.1 psia (0.069 N/cm^2), a safe limit for the hot surface, the most energetic ignition source. This curve is considered to represent a conservative ignition limit for O_2/H_2 mixtures assuming an ideal ignition source.

Figure 4.4-6 shows how pressure/H_2 concentration varies in a compartment initially filled with pure H_2 at 400R (222K) to which O_2 at 400R (222K) is added. This is conservatively representative of the situation during reentry after RTLS dump where Orbiter compartments may contain some H_2 from dump infiltration, to which air is added. Superimposed on this data is the H_2/O_2 flamability boundary derived above. It can be seen that for initial compartment pressures below 0.02 psia (0.0138 N/cm^2), concentration is outside the ignition boundary for all pressure levels.

Since all orbiter compartments are sealed during the dump period, it is unlikely that H_2 leaking into compartments from outside could build partial pressure to a substantial fraction of the ambient pressure. Therefore, the assumption of pure H_2 at end-of-dump ambient pressure in all compartments is conservative. Figure 4.4-7 summarizes trajectory data for RTLS abort.

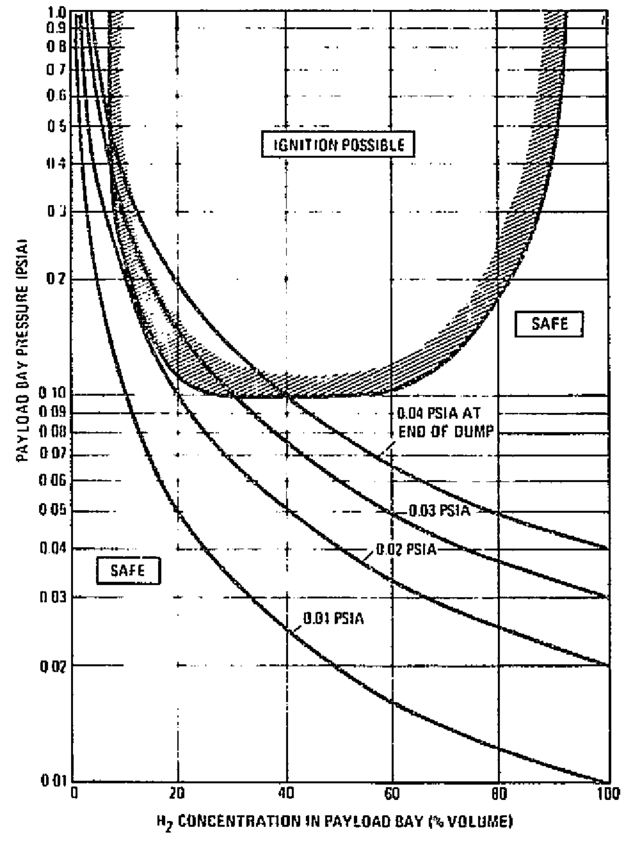


Figure 4.4-6. RTLS Abort Hydrogen Dump Considerations

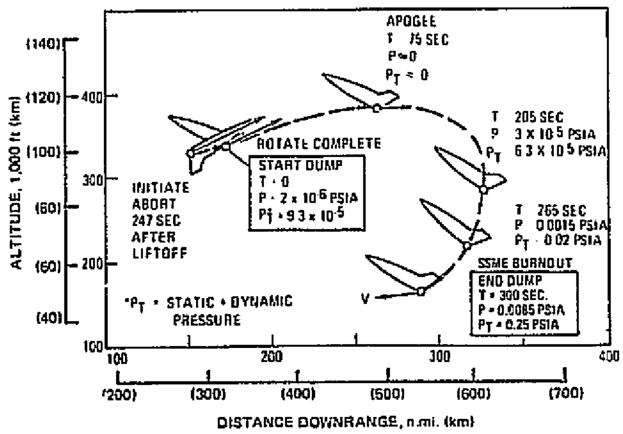


Figure 4.4-7. RTLS Abort Trajectory Data

It can be seen that ambient pressure is below 0.01 psia (0.0069 N/cm^2) through SSME burnout. Therefore, H_2 concentration would remain in the safe zone at all times during an RTLS abort.

An additional abort dump concern was the wetting and possible overcooling of external Orbiter surfaces with dumped liquid propellant, possibly leading to damage of the Orbiter structure. This problem has been investigated in detail, both experimentally and analytically by Convair under two studies sponsored by NASA/MSFC during 1966-1968. The initial study, "NAS8-20165, Development of Analytical Methods for Predicting Residual Cryogenic Propellant Behavior in Orbital Vehicles" developed a computer oriented two-phase plume flow field and impingement analytical model. The second study, "NAS8-21210, Emergency Propulsive Propellant Venting Systems Concepts" actually performed an extensive series of experiments in which hydrogen with the full range of fluid quality was dumped through a nozzle to vacuum conditions. The test program was designed to specifically simulate the dumping of cryogenic propellants to a space environment.

The thermodynamic process which occurs in the dumped fluid is shown in simplified form on the temperature-entropy diagram of Figure 4.4-8. The propellant leaves the tank at essentially saturated liquid conditions (point A) and flashes to a two-phase (liquid/gas) mixture as the pressure decreases to the dump exit conditions (point B), as discussed in Appendix C. Further expansion to the triple point pressure (point C) of the fluid occurs as the plume forms external to the dump nozzle where all three phases exist. Further expansion causes the liquid to freeze and a two-phase (solid/gas) plume to exist. The analytical studies verified by the hydrogen dumping experiments showed the two-phase portion of the plume to be essentially conical in nature and not spherical as sometimes erroneously assumed. Centaur flight data on dumping

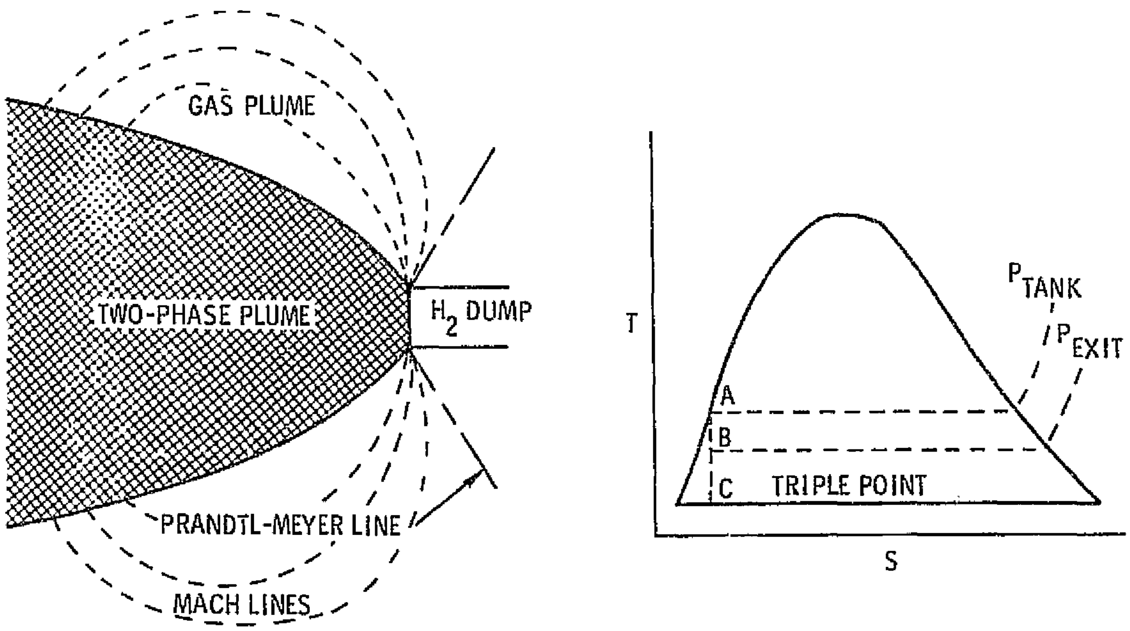


Figure 4.4-8. LH_2 Dump Characteristics

both H_2 and O_2 have confirmed the vacuum chamber data, proving that no wetting occurs as long as the surfaces are not located directly in the essentially conical two-phase plume. Gas expansion at the nozzle edge will occur to the angle determined by the Prandtl-Meyer line for the fluid; however, the thermodynamic effect due to impingement of the rarified gas is insignificant.

4.4.2.2 Dump Pressure/Diameter Optimization. Propellant dump for the baseline Tug is accomplished by pressurizing the propellant tanks and dumping both main propellants through lines that exit the Orbiter through the T-0 panels. Configuration of the entire dump system, including an assumed routing of the Orbiter-mounted portions of the lines are shown in Figures 4.4-9 and 4.4-10. The dump pressure and dump line diameter requirements are mutually dependent; i.e., the use of higher pressure results in smaller line diameter requirements. Trade studies were made to determine the optimum pressure/diameter combinations. Assumptions and data used in the trade study are summarized in Table 4.4-4.

Diameter Requirements. Dump flow as a function of tank pressures and line diameters was determined using the computer model discussed in Appendix C. This model calculates the maximum flow for a system with a flow exit to vacuum, assuming sonic flow (choking) of a two-phase gas/liquid mixture at the exit and no choked flow sections upstream of the exit. Since both the LH_2 and LO_2 dump lines have a large vertical drop and are under high acceleration (F/W) during RTLS dump, the total pressures at the top of the lines are substantially lower than at the exit. This is particularly true for LO_2 because of its high density. For this reason, the dump lines were checked for choking in the vicinity of the tank outlets.

The Orbiter exit was found to be the control section for the LH_2 system (exit chokes before the tank outlet) allowing use of a constant diameter line from outlet to exit. For the LO_2 system, the tank outlet section was found to choke before the Orbiter exit at low liquid levels near the end of dump. To obtain the required flowrates, the duct diameter required in the vicinity of the propellant tank outlet is larger than at the exit. This larger diameter must be maintained down the line to a point where increasing pressure due to increasing elevation head offsets the frictional pressure loss, allowing a reduction in diameter, which can be maintained to the exit. For this reason, the outlet duct design should be as clean (low ΔP) as possible and should drop at the fastest possible rate (maximum slope). The cleanest practicable outlet line design was assumed, but the baseline routing with "inverted" pickup and horizontal run to the vicinity of the disconnect was used for the optimization analysis.

For this configuration, shown in Figure 4.4-11, the larger outlet diameter must be maintained past the Tug/disconnect, as shown. An alternative configuration without the inverted pickup, shown in Figure 4.4-12, is recommended.

Figure 4.4-13 gives flow capacity versus duct diameter and tank pressure for the baseline Tug tank outlet line (Figure 4.4-11). The required duct diameter is plotted versus tank pressure at the nominal dump rate specified in Figure 4.4-14.

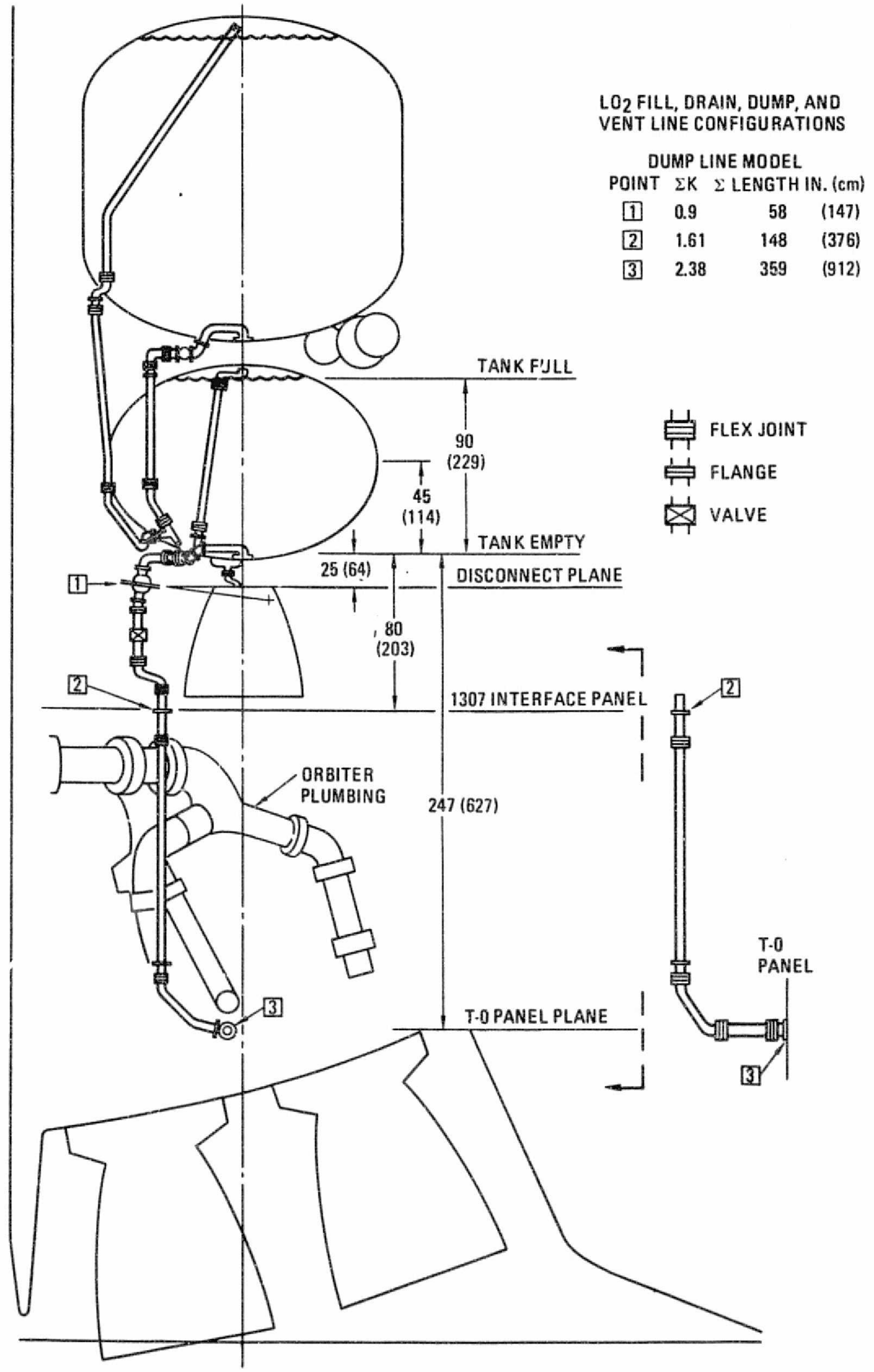


Figure 4.4-9. LO_2 Fill, Drain, Dump and Vent Line Configurations

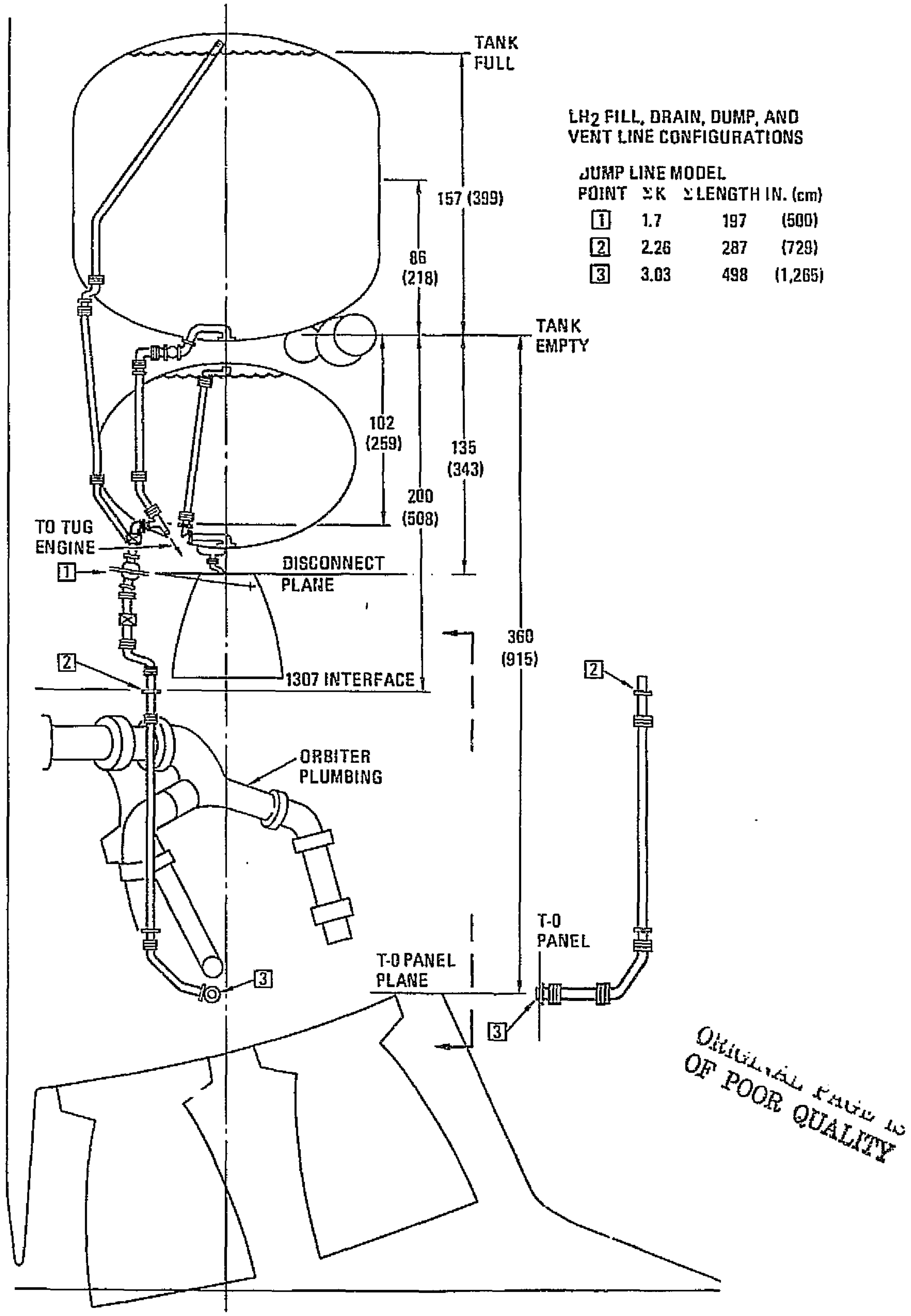


Figure 4.4-10. LH_2 Fill, Drain, Dump and Vent Line Configurations

Table 4.4-4. Dump System Optimization Study Data and Assumptions

Dump time (seconds)	300
Average Dump Flowrate, lb/sec (kg/sec)	
LH_2	25 (11.3)
LO_2	147 (66.7)
Shuttle Acceleration (F/W)	
Initial	1.0
Final	3.0
Propellant Vapor Pressure, psia (N/cm^2)	
LH_2	15.5 (10.7)
LO_2	15.5 (10.7)
Dump Lines	
Configuration	(See Figures 4.4-8 and 4.4-9)
Construction LO_2	Aluminum, uninsulated
LH_2	Stainless steel, vacuum jacketed
Pressurization System	
Type	Ambient helium
System Weight	10 lb/lb (kg/kg) usable helium
Tug Propellant Tank Weight Sensitivity	
LH_2	18 lb/psia (8.16 $kg/N/cm^2$)
LO_2	8 lb/psia (3.65 $kg/N/cm^2$)

Figure 4.4-15 gives LO_2 dump system flowrate capacity versus adapter/Orbiter duct diameter and tank pressure. The dump duct diameter from tank exit through the disconnect are as given in Figure 4.4-14. For the 16.0 (11.03 N(cm^2) psia tank pressure, data is given for both initial (F/W = 1.0, tank full) and final (F/W = 3.0, tank empty) conditions. The final flowrate is 25-45 percent higher than the initial, and at the average F/W of 1.5, the flow is approximately 13 percent above the initial. Based

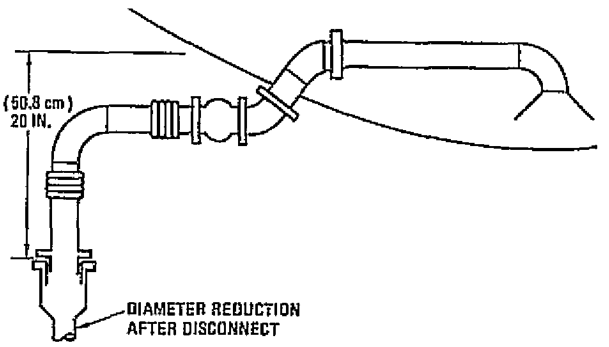


Figure 4.4-11. Outlet Duct Design

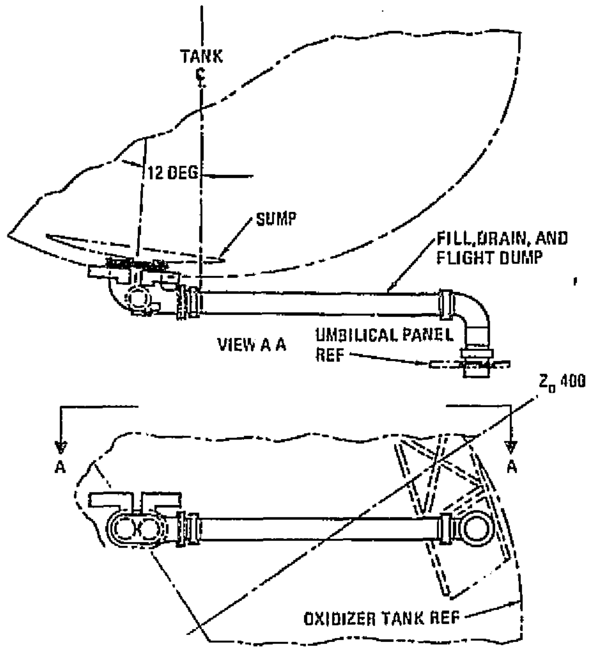


Figure 4.4-12. Recommended LO_2 Tank Outlet Configuration

on this data, the design flowrate at the 1.0 F/W initial condition is 130 lb/sec (145/1.135) (59 kg/sec) as indicated in Figure 4.4-14. Adapter/Orbiter line diameter requirements are determined at this design flowrate.

Figure 4.4-16 gives LH_2 system dump flowrate capacity versus duct diameter (from tank outlet to exit, in this case) and tank pressure. Data is given for vehicle F/W = 0 at tank pressures from 16.2 to 20.0 psia (11.2 to 13.8 N/cm^2) and for F/W = 2.25 (near final condition) at 18.0 (12.4 N/cm^2) psia tank pressure, representing a typical RTLS condition. The RTLS rate is approximately 10 percent higher than the zero-g rate. Since the mechanics and expense of running the RTLS dump cases are much greater than the zero-g cases, diameter requirements are estimated from the zero-g data at a design flowrate of 23 lb/sec (10.4 kg/sec) — 90 percent of the RTLS design flowrate of 25 lb/sec (11.3 kg/sec) as shown.

Pressurization System Requirements. Dump pressurant requirements were determined using the Epstein-hand calculation technique from Reference 3 programmed for the Hewlett-Packard 9810 computer. Film coefficient data used is given in Figure 4.4-17 (from Reference 4). This technique allows calculation of a collapse factor (CF) which when multiplied by the ideal quantity of helium pressurant required (assuming equal storage and propellant tank temperature) yields the actual requirement.

Data and assumptions used to determine pressurant requirements are summarized in Table 4.4-5. Values of CF versus tank pressure for both LH_2 and LO_2 tanks are shown in Figure 4.4-18. The resulting helium system weight requirements are given in Table 4.4-6.

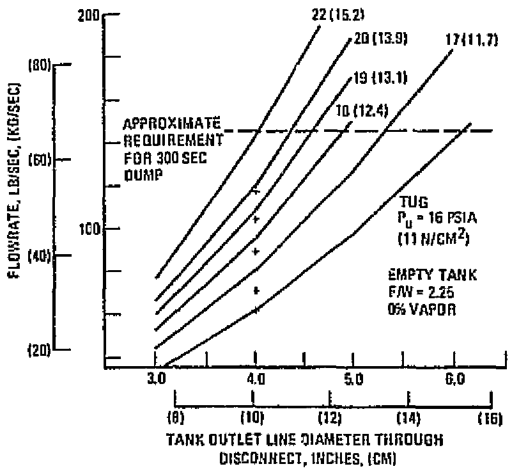


Figure 4.4-13. Flow Rate vs Duct Diameter and Tank Pressure

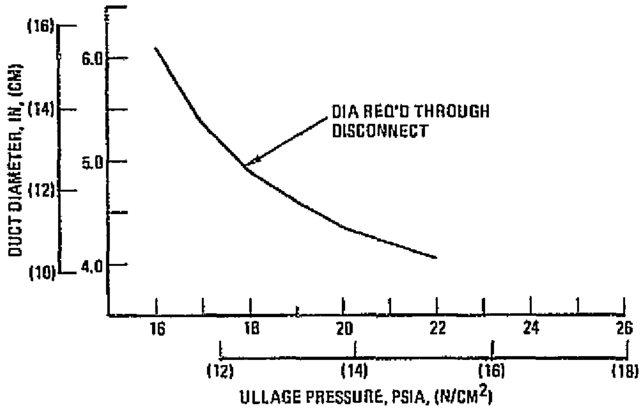


Figure 4.4-14. LO_2 Outlet Line Duct Diameters Required for 300-Second Dump Time

Dump Line Weights. The dump line model assumed for weight analysis is summarized in Table 4.4-7. Weights for the ducts were calculated and component weights were scaled from data for similar Atlas and Centaur components.

Tank Weight. Tank weight sensitivities to design pressure were assumed to be 18 and 8 lb/psi (8.16 and 3.63 kg/N/cm^2) for LH_2 and LO_2 respectively. These sensitivities were developed for a similar baseline Tug in the STSS (cryogenic) of Reference 5. It was not clear that changes in dump pressure requirements would necessarily change

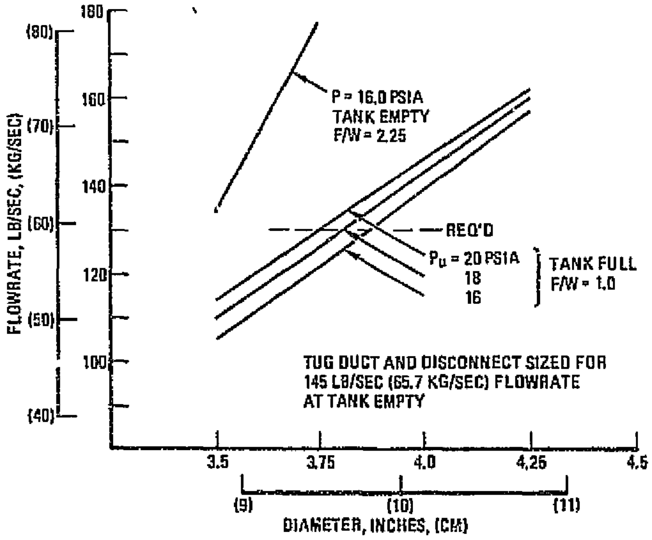


Figure 4.4-15. LO_2 Flow Rate vs Duct Diameter

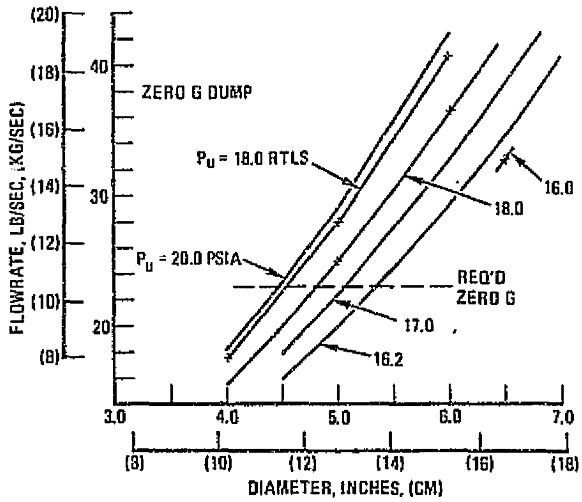


Figure 4.4-16. LH_2 Dump Flow Rate vs Duct Diameter and Tank Pressure

Table 4.4-5. Data and Assumptions Abort Pressurant Weights

Assumptions:

Both tanks saturated at 15.5 psia (10.7 N/cm^2)

Pressurization with ambient helium T = 520R (T = 289K)

Dump time 300 seconds

Tank material aluminum alloy

Wall gage, in. (cm)

LH_2 0.041 (0.104)

LO_2 0.038 (0.097)

External heat transfer negligible

Helium required

$$W_{HE} = (CF) \frac{PV}{RT}$$

where P = tank pressure

V = total tank volume

R = 386 (helium gas constant)

T = He supply temp = 520R (289K)

and CF = collapse factor based on Epstein analysis (Ref. 3).

Tank volumes, ft^3 (m^3)

LO_2 640 (18.1)

LH_2 1748 (50)

tank design pressures, since other pressure requirements (run pressurization, lockup during ascent and entry) must be considered. For this reason the trades were made assuming both a one-to-one and a zero effect of dump pressure on tank design pressure.

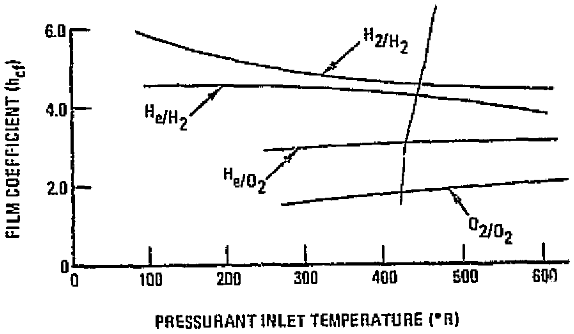


Figure 4.4-17. Film Coefficient vs Pressurant Inlet Temperature

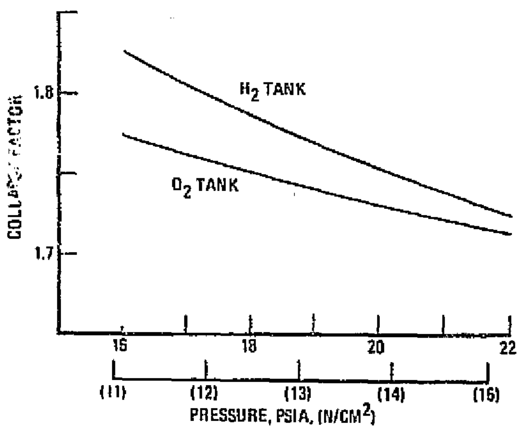


Figure 4.4-18. Collapse Factor vs Tank Pressure Abort Dump

Results. Results of the trade study are summarized in Figures 4.4-19 and 4.4-20. The following observations can be made about this data:

a. Minimum weight for Orbiter supplied and carried hardware (between T-0 and 1307 interface) is obtained at the highest LH_2 tank pressures considered. If this hardware is permanently installed in the Orbiter for all missions rather than as kits for Tug missions only, this may be of significance.

b. Maximum payload for Tug missions is obtained at approximately 18 psia (12.4 N/cm^2) tank pressures for both LO_2 and LH_2 if tank design pressure has a one-to-one correspondence to dump pressure. However, payload variations over the range of pressures considered is small.

c. Maximum payload for Tug missions is obtained at the higher tank pressures if there is no effect on tank design pressure. This is because increasing pressure reduces all weights except the helium system, which being Orbiter retained has a low payload sensitivity ($\frac{\partial PL}{\partial INERT}$ = 0.36).

It can be concluded that the maximum dump pressure that can be used without affecting tank design pressure should be selected. These pressures were assumed to be the 17 and 18 psia (11.72 and 12.4 N/cm^2) pressures defined for the baseline LO_2 and LH_2 tanks respectively.

4.4.2.3 Orbital Abort. Abort once around (AOA), abort to orbit (ATO), and abort from orbit (AFO) are termed orbital aborts because propellant dump takes place at

Table 4.4-6. Helium Requirements for Abort Pressurization

Tank Pressure, psia (N/cm^2)	Usable Helium Required, lb (kg)		Helium System Weight, lb (kg)	
	LO_2	LH_2	LO_2	LH_2
16 (11.03)	13.04 (5.9)	37.15 (16.9)	142 (64.4)	403 (182.8)
17 (11.22)	13.75 (6.2)	38.94 (17.7)	149 (67.6)	423 (191.9)
18 (12.4)	14.47 (6.6)	40.75 (18.5)	157 (71.2)	442 (200.5)
20 (13.8)	15.89 (7.2)	44.3 (20.1)	172 (78)	481 (218.2)
24 (16.5)	18.7 (8.5)	51.23 (23.2)	203 (92.1)	556 (252.2)

Table 4.4-7. Dump Line Model for Weight Analysis

Item	LO_2	LH_2
Length, in. (cm)	359 (911.9)	488 (1239.5)
Tug	58 (147.3)	195 (495.3)
Adapter/Orbiter	301 (764.5)	293 (744.2)
Insulation	bare	Vacuum Jacket
Material	aluminum	CRES
Min wall gage, in. (cm)	0.040 (0.101)	0.030 (0.076)
No. flex joints		
Tug	3	6
Adapter/Orbiter	7	7
No. flanges		
Tug	3	4
Adapter/Orbiter	4	4
No. valves		
Tug	2	2
Adapter/Orbiter	2	2

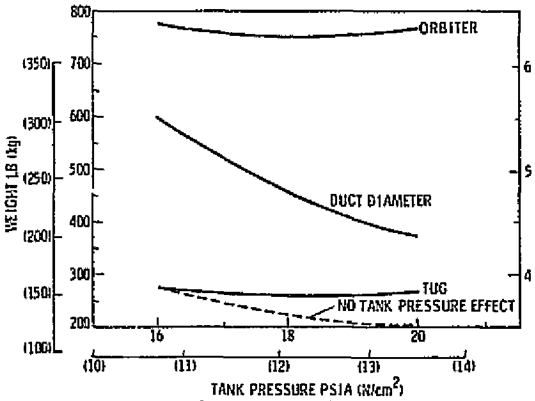


Figure 4.4-19. LH_2 Dump Pressure Optimization

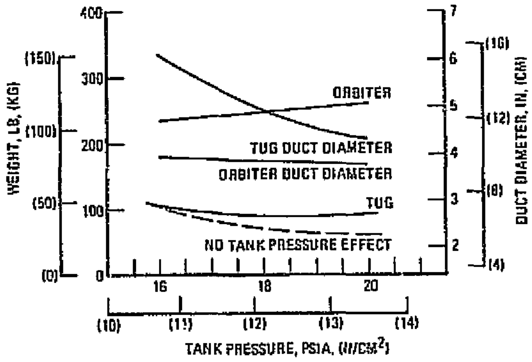


Figure 4.4-20. LO_2 Dump Pressure Optimization

orbital or slightly sub-orbital velocities. The abort dump operation differs from the RTLS(1) in these major respects:

a. The F/W is much lower — from zero to a maximum of 0.055, the latter obtainable through operation of the orbit maneuvering system (OMS) with 12,000 lb (53376N) thrust.

b. The time available is longer, with minimum available of 3500 seconds for AOA.

The baseline abort systems designed for the 300 second RTLS dump will have longer dump times for orbital aborts, as shown in Table 4.4-8. At the same tank pressures, flow rates are reduced and dump times extended because of reduction in physical head pressure available at the lower F/W. The flowrate reduction and resulting time extension are large for LO_2 because of the high density and are low for LH_2 because of the low density. The resulting times of 1070 and 330 seconds for LO_2 and LH_2 respectively are well below the minimum available time of 3500 seconds.

There is a potential problem of high residuals attendant to low-g propellant expulsion. The high residuals are caused by plenomena normally called either pullthrough or dropout, which at low F/W cause ingestion of the pressurizing gas and loss of tank pressure with a relatively high level of liquid in the tanks. LO_2 and LH_2 residuals were calculated for a range of orbital dump flowrates and acceleration levels appropriate for orbital aborts. Assumptions and data used in these calculations are summarized in Table 4.4-9. Pullthrough heights were calculated using the lowest value obtained from the two equations shown. Equation 1 from Reference 6 is applicable at the lowest F/W considered (dump thrust settling), while Equation 2 from Reference 7 generally applied in the range of F/W obtainable using RCS or OMS settling. At the

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(1) For aborts between approximately 220 and 240 seconds after launch, the Orbiter may elect either the RTLS or AOA mode. Dumps for AOA initiated in this period can be made using the RTLS technique, if desired.

Table 4.4-8. Comparison of RTLS and Orbital Abort Dump Flowrates

Item	LO_2	LH_2
Design Condition		
Abort Mode	RTLS	RTLS
Dump Time, sec	300	300
Average Flowrate, lb/sec (kg/sec)	147 (66.7)	25 (11.4)
Tank Pressure, psia (N/cm^2)	17 (11.7)	18 (12.4)
Orbital Abort Performance		
Average Flowrate, lb/sec (kg/sec)	43 (19.5)	22.7 (10.3)
Dump Time, sec	1070	330
Tank Pressure, lb (kg)	17 (11.7)	18 (12.4)

higher F/W levels pullthrough heights can be reduced by use of a properly designed sumps. Design of sumps was outside the scope of this study, so anti-pullthrough (ATPT) plate sumps of the type defined in Reference 7 were assumed. Residual data was calculated for a range of ATPT plate diameters.

Residuals as function of final thrust (Orbiter thrust at Tug dump completion), dump time, and ATPT plate diameter are shown in Figures 4.4-21 and 4.4-22. The following observations can be made about this data:

a. Residuals for settling thrust levels below approximately 500 lb (227 kg) are prohibitively large and approach the tank capacity asymptotically.

b. Residuals are a strong function of dump time. They are generally excessive for dump times shorter than 800 seconds but are reduced to the practicable minimum at 1200 seconds.

c. LO_2 residual is a strong function of ATPT plate diameter below 1.5 feet (0.46 m), with the practicable minimum obtained at about 2.0 feet (0.61 m).

These data and observations suggest the use of dump sumps of relatively large diameter, dump times of about 1200 seconds, and a final vehicle settling thrust above 3000 lb (13344N) to obtain minimum practicable residuals. The RCS thrusting time available in Table 4.4-9 assumes all RCS propellant except that required for reentry attitude control is available for settling. The OMS time given assumes all thrusting

Table 4.4-9. Assumptions and Data for Orbital Dump Residual Analysis

Settling Thrust/Time Options

	Thrust, lb (N)	Time, sec
OMS	12000 (53376)	310 max
RCS	3600 (16,000)	250 max
LO_2 Dump	0 to 260 (1156) max	Entire dump
LH_2 Dump	0 to 300 (1334) max	Entire dump

Weights, lb (kg)

Orbiter	-	150,000 (68038) dry
	+	6,000 (2722) 1/2 of OMS/RCS/etc
		156,000 (70760)
Tug	-	5,755 (2610) burnout
		500 (227) 10 sec of propellant (dump)
		6,255 (2837)
Payload	-	10,000 (4536)
TOTAL	=	173,000 lb (78741)

Pullthrough Heights

$$H_C = \left[\frac{Q^2}{6.5\frac{F}{W}g}\right]^{1/5} \quad \text{(Equation 1)}$$

or

$$H_C = 1.5\left[\frac{Q^2}{\frac{F}{W}g\pi^2D^2}\right]^{1/3} \quad \text{(Equation 2)}$$

where

Q = flowrate, ft^3/sec

D = Sump diameter, ft

time remaining after orbital circularization, including the deorbit time of 100 seconds, is available. It can be seen that the maximum total time (sum of OMS and RCS) above 3000 lb (1334 kg) thrust is 560 seconds, less than one-half the desired time of 1200 seconds. The only other settling thrust available is that which could be produced by proper use of the dumped Tug propellant. This would require redirecting the dump, which in the baseline would produce near-cancelling yaw thrusts, to an axially aft direction. If this redirection is made with 100 percent efficiency, maximum thrust available would be about 360 lb (1600N) (260 lb LO_2 and 100 lb LH_2) for a 1200 second dump.

Assuming use of the dump thrust of 360 lb (1600 N) maximum for sustaining thrust during the major portion of dump, thrust would have to be increased before depletion to avoid the high residuals indicated in Figures 4.4-21 and 4.4-22. Thrust would have to be increased before initial pullthrough gas ingestion at the low thrust and continued to depletion at the higher thrust. Time required at the increased thrust is shown in Figures 4.4-23 and 4.4-24. At the maximum dump thrust of 360 lb (1600N) for the 1200 second dump, the time required is approximately 38 seconds. If actual dump thrust is reduced to 50 percent of the maximum available value due to inefficiency in the redirection, time required would increase to about 50 seconds. Thrust values substantially less would probably be unacceptable.

The low g dump flowrate for the baseline LO_2 system is given in Figure 4.4-25. The zero-g dump time of 1090 seconds is very close to the desired 1200 seconds using the RTLS system and procedures, so no changes are required. The low-g LH_2 flowrate is only 10 percent lower than that for RTLS at the same tank pressure, so modifications are required to reduce flowrate for the desired dump time. If the LH_2 tank is not pressurized during low-g dump (i.e., self-pressurization is used), average flowrate would decrease to approximately 18 lb/sec (8.2 kg/sec), extending dump time to 460 seconds. The best solution for further extension of time appears to be the

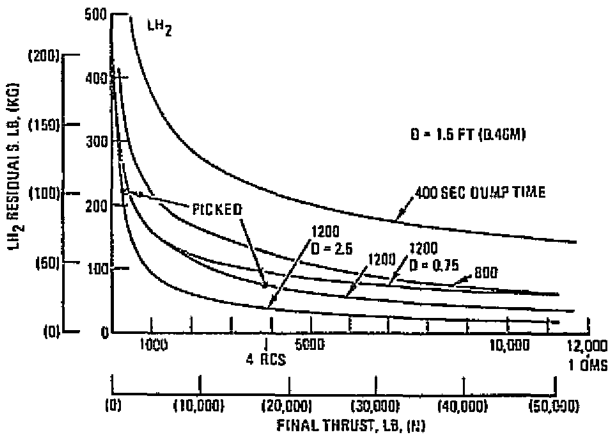


Figure 4.4-21. LH_2 Residual vs Dump Time and Thrust, Orbital Abort

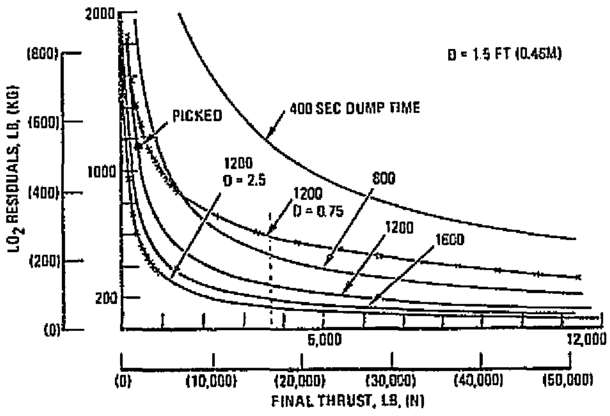


Figure 4.4-22. LO_2 Residual vs Dump Time and Thrust, Orbital Abort

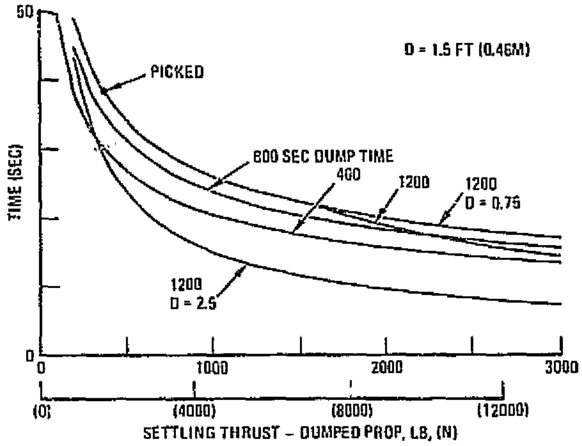


Figure 4.4-23. OMS/RCS Thrusting Time vs LH_2 Dump Time and Settling Thrust Orbital Abort

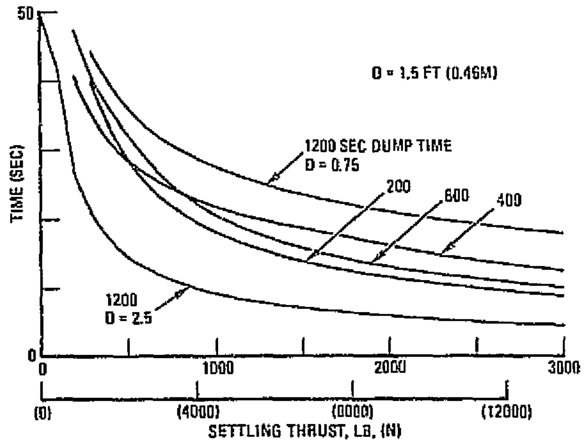


Figure 4.4-24. OMS/RCS Thrusting Time vs LO_2 Dump Time and Settling Thrust Orbital Abort

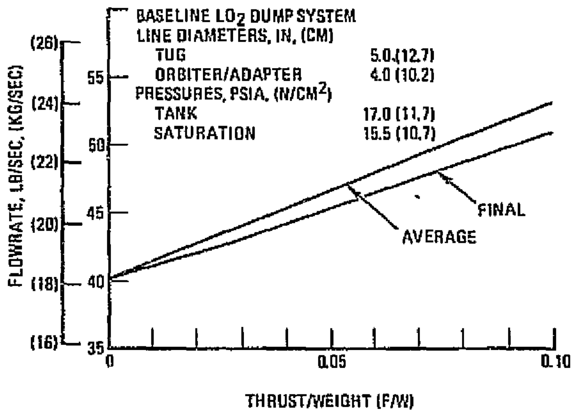


Figure 4.4-25. LO_2 Orbital Dump Flowrate vs Thrust/Weight

insertion of a reduced diameter exit for low-g dump, possibly incorporated in the same device effecting the desired aft redirection of the flow. Effective flow area of the required device would be approximately equivalent to a 2.0-inch (5.1 cm) diameter pipe. Further definition of the device was not pursued since it would be Orbiter-supplied. Addition of a controllable restriction in the deployment adapter portion of the line probably would be unacceptable because of probability of inducing damaging pressure oscillations in system downstream of the restriction.

Recommendations based on the foregoing analyses are as follows:

a. Use an orbital abort dump time of 1200 seconds.

b. Extend the LH_2 dump time to 1200 seconds by 1) nonpressurization of Tug LH_2 tank, and 2) restricting the dump exit to the approximate equivalent of a 2-in. (5.1 cm) diameter.

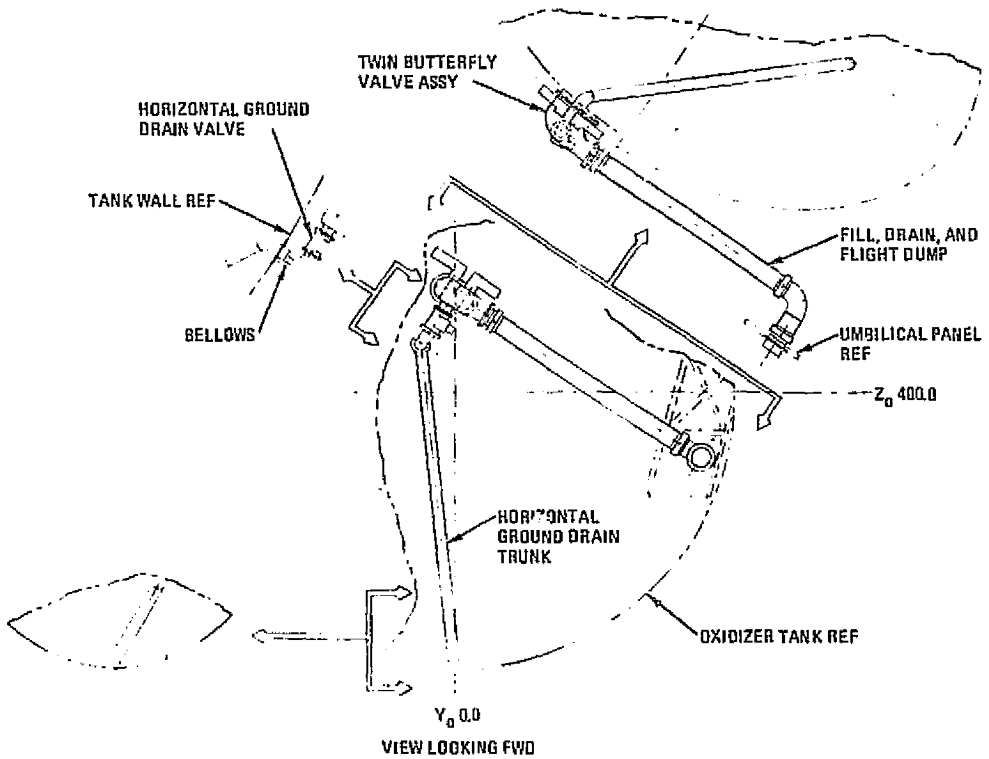


Figure 4.4-26. Oxidizer Fill, Drain, Flight Dump, and Horizontal Ground Drain Arrangement

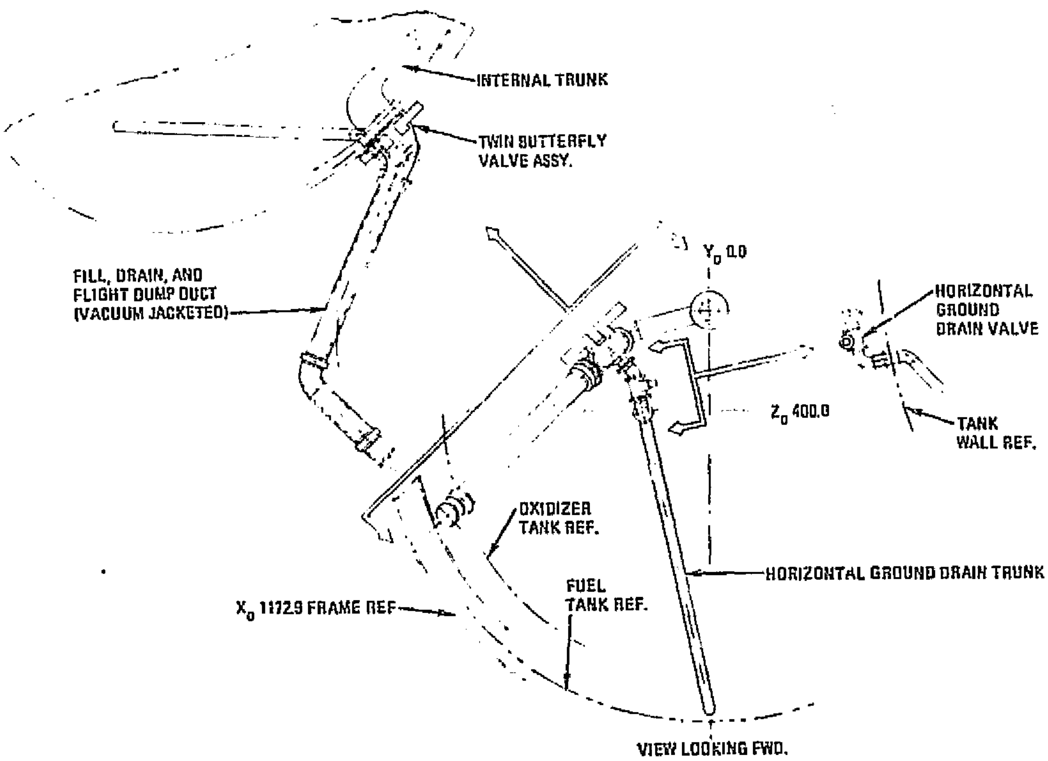


Figure 4.4-27. Fuel Fill, Drain, Flight Dump, and Horizontal Ground Drain Arrangement

4.4.3 CONTROL TRADE STUDY. Three of the Tug service lines have possible requirements for alternative routing on the downstream (Orbiter) side of the Tug/deployment adapter disconnects:

a. LH_2 Vent. Requires a connection to ground at the T-0 panel for safe disposal of prelaunch vented H_2, and an alternative path to a vertical tail or wing trailing edge vent exit for safe flight and post-landing venting.

b. LO_2 and LH_2 Abort Dump Exits. Propellant dump for AOA, ATO, and AFO requires the use of dump exits that produce axial thrust for propellant settling. This requirement is generated because the low-g dump time of 1200 seconds is substantially longer than the time available for settling using the Orbiter RCS or OMS as discussed in Section 4.4.2.3. RTLS abort dump is through the side-facing T-0 panel (common with the fill and drain exits) to minimize interaction with the Orbiter main engine exhausts, and no axial thrust is produced. Active controls are required to either 1) direct the dump flow in the aft direction from the T-0 panels, or 2) reroute the low-g dump through the Orbiter in an aft-facing location.

The active controls required to select the required flow path for the vent and for the aft-facing orbital dumps may be mounted in either the Orbiter or Tug deployment adapter. Adapter mounting avoids the requirement for active controls in the Orbiter, and Orbiter mounting minimizes the number of adapter/Orbiter interfaces. Figure 4.4-28 shows typical line routing and configuration for the two alternative approaches. Also shown are interface and component counts and weights for all three service lines.

The Orbiter mounted approach is simpler (fewer interfaces and components) and lighter by 139 lb (63 kg). However, since the weight of the Tug is not affected (all Δ weight remains with the Orbiter) the payload effect is small. The final evaluation of this trade and selection of the solution should be the responsibility of NASA and RI.

4.4.4 FILL, DRAIN, DUMP AND TOPPING LINE DIAMETER INSULATION REQUIREMENTS. Flow requirements and approximate diameter and temperature rise limits for the fill, drain, topping and dump functions are as follows:

Function	Required Flowrate lb/sec (kg/sec)	Minimum Dia. Required, in (cm)	Max Desired ΔT, °R (°K)
LO_2 Fill, Drain	24.5 (11.1)	2.0 (5.1)	0.6 (0.33)
Dump	147 (66.7)	4.0 (10.2)	—
Topping (min)	0.15 (0.06)	0.75 (1.4)	0.6 (0.33)
LH_2 Fill, Drain	4.14 (1.9)	2.0 (5.1)	0.2 (0.11)
Dump	25 (11.3)	5.0 (12.7)	—
Topping (min)	0.2 (0.091)	0.75 (1.9)	0.2 (0.11)

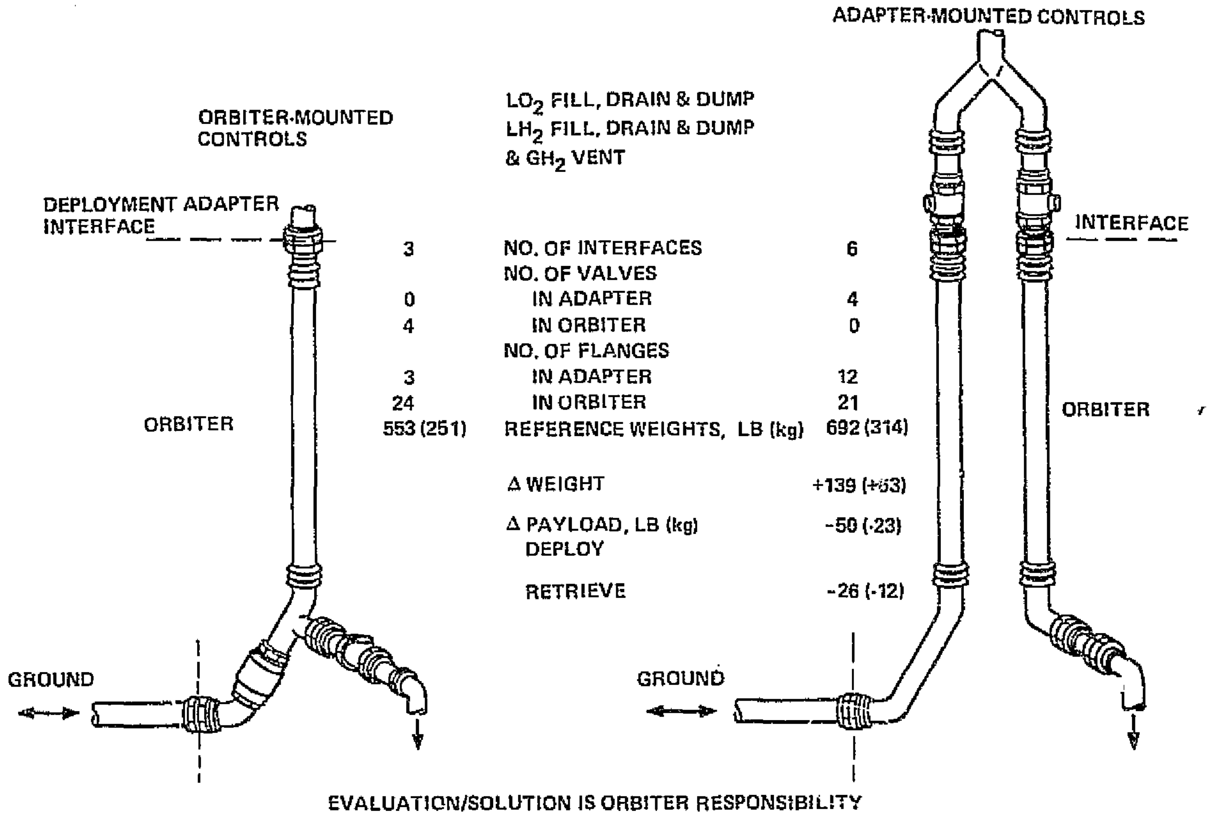


Figure 4.4-28. Alternative Line Routing Configuration

A study was made to determine if a single common line for each propellant can be used for all functions or if separate smaller lines are required to meet the temperature limits for fill and/or topping. It was assumed that all LH_2 lines would be vacuum jacketed to prevent liquid air formation regardless of ΔT requirements, but that LO_2 line insulation would be tailored to the ΔT requirements. Only foam insulation of appropriate thickness and vacuum jacketing were considered for the LO_2 lines. After preliminary analysis it was established that ΔT at fill and drain rates were compatible with use of the dump line diameter, but that ΔT at topping rates were higher than desired.

The final selections were made on the basis of a trade between the following alternatives.

a. Top through vacuum jacketed fill, drain, and dump lines and increase the design tank saturation pressures for compatibility with high ΔTs.

b. Add separate topping lines of smaller diameters and use lower tank saturation pressures, permissible at lower ΔTs. In this case, no LO_2 F, D&D line insulation is required, and the LO_2 topping line can be either foam or vacuum insulated.

Major assumptions and data used in the study are:

a. The topping propellant arrives at the Tug at a temperature equal to or less than saturation temperature at the design prelaunch tank pressure.

b. The correlary of a above — the design prelaunch propellant tank and propellant saturation pressures are equivalent to saturation at the topping temperature.

c. Topping propellant arriving at the T-0 panel is at a temperature equivalent to saturation at 15.0 psia.

d. Heat leak for LH_2 and LO_2 vacuum jacketed Orbiter lines is 15.2 Btu/hr-ft^2 (47.9 W/M^2). This is the unit heat leak for the current Orbiter 5-inch-diameter (13 cm) LH_2 F, D&D line with three bayonet joints for ease of kit implementation, assumed to apply to any line diameter.

e. Heat leak for adapter and Tug mounted vacuum jacketed lines without bayonet joints is 8 Btu/hr-ft^2 (25.2 W/M^2), the average heat leak for the 10-inch (25.4 cm) diameter S-IVB LH_2 feed line installation supplied by Stainless Steel Products.

f. Thermal conductivity of foam insulation used is 0.13 Btu/hr-ft^2-°R(0.74 W/M^2-°K).

g. Tank weight partials with respect to pressure are 18 and 8 lb/ psi (11.8 and 5.26 kg (N/cm^2) for LH_2 and LO_2 respectively.

Results of the study are summarized in Table 4.4-10. Use of the vacuum jacketed common line was selected for LH_2 because it was lighter (50 lb (22.7 kg) deployment payload increase), and less hardware was required. In essence the trade was between 1) increased tank pressure (0.7 psi or 0.48 N/cm^2), or 2) an added vacuum jacketed line of 3/4 inch (1.9 cm) diameter, the latter decreasing payload capability.

Use of the separate LO_2 topping line was selected because it is lighter in weight (141 lb (64 kg) deployment payload increase); the required vacuum jacketed line was smaller and therefore considered less expensive. In essence the trade was between 1) a bare aluminum line of 4.0/5.0 in. (10.2/12.7 cm) diameter plus a 3/4-inch (1.9 cm) vacuum jacketed duct; and 2) a single 4.0/5.0 in. (10.2/12.7 cm) diameter vacuum jacketed duct, the latter causing additional payload penalty.

4.4.5 ALTERNATIVE MID-BODY VENT AND DUMP EXITS. Rockwell International is currently considering the use of mid-body exits (i.e., in the mid-fuselage forward of the 1307 bulkhead) for lines that do not require a connection to ground. Included in this category are:

a. Dump lines for both propellants.

b. Leakage vent lines for both propellants

c. GO_2 ground/flight vent.

Analyses were made to assess the impact of these changes on the baseline Tug and its interface equipment requirements. Figure 4.4-29 shows a schematic of the line routing and diameter for the baseline (T-0 exit) and the alternative (mid-body exit). Configuration of the lines within the Tug itself (i.e., from the disconnects forward) was assumed to be the same for both alternatives. Figure 4.4-30 shows the configuration of the complete LO_2 dump line from the tank outlet to the mid-body exit. The configuration of this line from the disconnect to the mid-body exit is typical for all lines analyzed.

Table 4.4-10. LH_2 and LO_2 Topping Line/Insulation Trade Study

Item	Common Line*	Separate Line
LH_2 Line Dia, in. (cm)		
F, E & D	5.0 (12.7)	5.0 (12.7)
Topping	—	0.75 (1.9)
Topping ΔT, °R (°K)	0.4 (0.222)	0.12 (0.067)
Saturation Pressure, psia (N/cm^2)	16.0 (11)	15.3 (10.54)
LH_2 Density, lb/ft^3 (kg/M^3)	4.398 (70.448)	4.41 (70.641)
Propellant at Constant Tank Vol, lb (kg)	-18.2 (-8.3)	Ref
Residual Gas, Weight lb (kg)	+4.73 (2.1)	Ref
Tank ΔWt, lb (kg)	12.6 (+5.7)	Ref
Line ΔWt, lb (kg)		
Tug	Ref.	+44.4 (20.1)
Orbiter/Adapter	Ref.	+34.4 (15.6)
Payload, lb (kg)		
Deploy	+49.4 (22.4)	Ref.
Retrieve	+21.5 (9.8)	Ref

*Common line selected. Less hardware, greater payload capability.

Table 4.4-10. LH_2 and LO_2 Topping Line/Insulation Trade Study (Contd)

Item	Common Line	Separate Line*
LO_2 Line Dia, in. (cm)	(10.2/12.7)	
F, D & D	4.0/5.0†	4.0 (10.2)/ 5.0 (12.7)
Topping	—	0.75 (1.9)
Insulation		
F, D & D	Vac Jacket	None
Topping	—	Vac Jacket/Foam
Topping ΔT, °R (°K)	2.05 (1.14)	0.576 (0.315)
Saturation Pressure , psia (N/cm^2)	16.82 (11.59)	15.51 (10.69)
LO_2 Density, lb/ft^3 (kg/M^3)	70.81 (1134.3)	71.06 (1138.3)
Propellant at Constant Tank Vol, lb (kg)	-148 (-67.1)	Ref
Residual Gas Weight, lb (kg)	+14.5 (6.6)	Ref
Tank ΔWeight, lb (kg)	+10.5 (4.8)	Ref
Line ΔWeight, lb (kg)		
F, D & D		
Tug	+28.5 (12.9)	Ref
Orbiter/Adapter	+95.8 (43.5)	Ref
Topping		
Tug	—	7.8 (3.5)
Orbiter	—	34.2 (15.5)
Payload, lb (kg)		
Deploy	-140.8 (68.9)	Ref
Retrieve	-73.9 (33.5)	Ref

*Separate line selected. Higher payload, smaller/less expensive vac jacket line (0.75 versus 4.0 in.) (1.9 versus 10.2 cm)

†Disconnect to Tug tank.

FUNCTION (BASELINE)	DIA IN.	DIA CM	CODE
LH_2 FILL, DRAIN & DUMP	5.0	12.7	1
GH_2 VENT (PRELAUNCH)	3.0	7.6	2
GH_2 VENT (IN-FLIGHT)	2.5	6.4	3
LH_2 TANK LEAKAGE VENT	0.75	1.9	4
N_2H_4 DRAIN & RELIEF	0.5	1.3	5
LO_2 FILL DRAIN & DUMP	4.0	10.2	6
LO_2 TOPPING	0.75	1.9	7
GO_2 VENT	2.0	5.1	8
LO_2 TANK LEAKAGE VENT	0.75	1.9	9
HELIUM SERVICE	0.38	0.96	10
OPTION			
LH_2 DUMP	4.8	12.2	1
LH_2 FILL, DRAIN & TOPPING	2.0	5.1	11
LO_2 DUMP	4.0	10.2	6
LO_2 FILL DRAIN & TOPPING	2.0	5.1	7

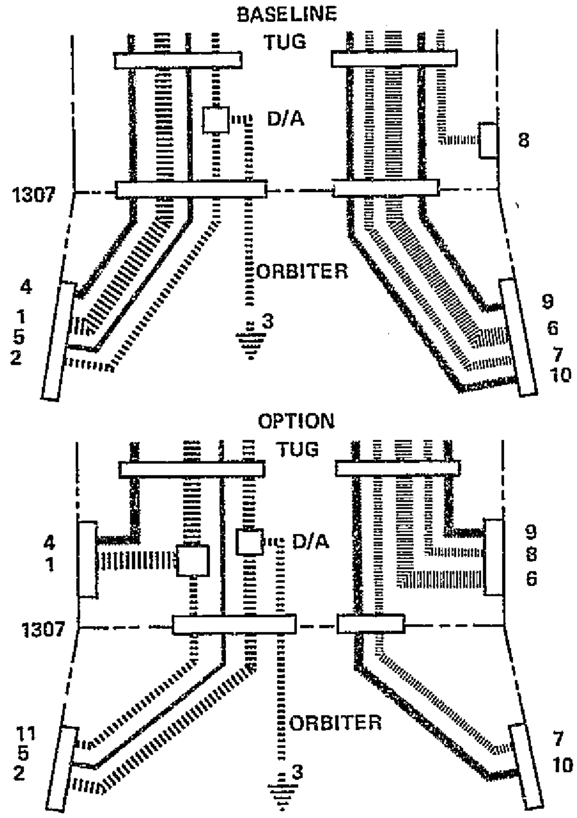
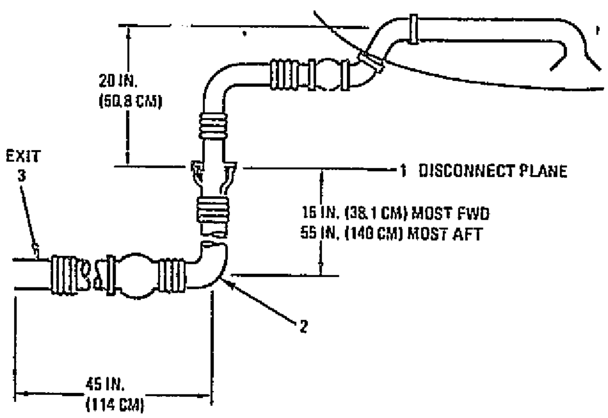


Figure 4.4-29. Comparison of Baseline and Mid-Body Exit Configuration



POINT	1	2	EXIT 3
ΣK	0.9	1.15	1.5
MAX/MIN LENGTH, IN.,(CM)	58 (147)	73 (185)/113 (287)	118 (300)/158 (401)
MIN HEAD, IN.,(CM)	20 (50.8)	35 (89)/75 (190)	35 (89)/75 (190)

ADDITIONAL HEAD
TANK FULL – 7.5 FT (2.28 M)
TANK 1/2 FULL – 3.75 FT (1.14 M)

Figure 4.4-30. Mid-Body Exit Oxidizer Dump System

Line sizing data for abort dump is summarized in Figures 4.4-31 and 4.4-32. LO_2 dump flowrate as a function of vehicle acceleration (F/W) and line diameter is given in Figure 4.4-31 for the most forward (just below disconnect panel) and most aft (just above 1307 bulkhead) mid-body exits. Reduction in height from the tank to the sonic exit reduces sensitivity of flowrate to F/W, so that flowrate during the RTLS dump (1.0 to 3.0g) is more nearly constant, decreasing slightly at the end rather than increasing as in the case of the T-0 exit. In addition, the orbital dump flowrate at near zero g is higher relative to the RTLS rate. Orbital dump time for a system designed for the RTLS 300-second dump time would be approximately770 seconds for the most aft exit and 670 seconds for the most forward exit. These times approach the maximum thrusting time available from the Orbiter, estimated at 310 and 250 seconds for OMS and RCS respectively (Table 4.4-9).

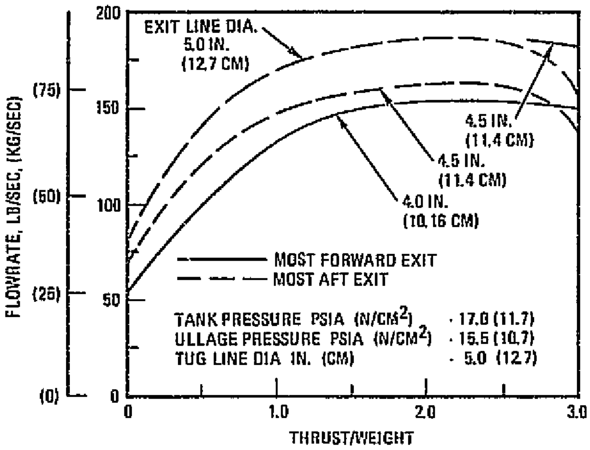


Figure 4.4-31. Mid-Body Exit Oxidizer Flowrate versus Acceleration and Duct Diameter

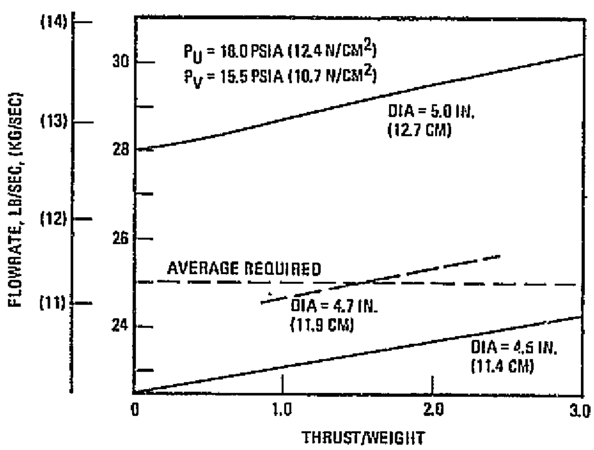


Figure 4.4-32. Mid-Body Exit Fuel Dump Flowrate versus Acceleration and Diameter

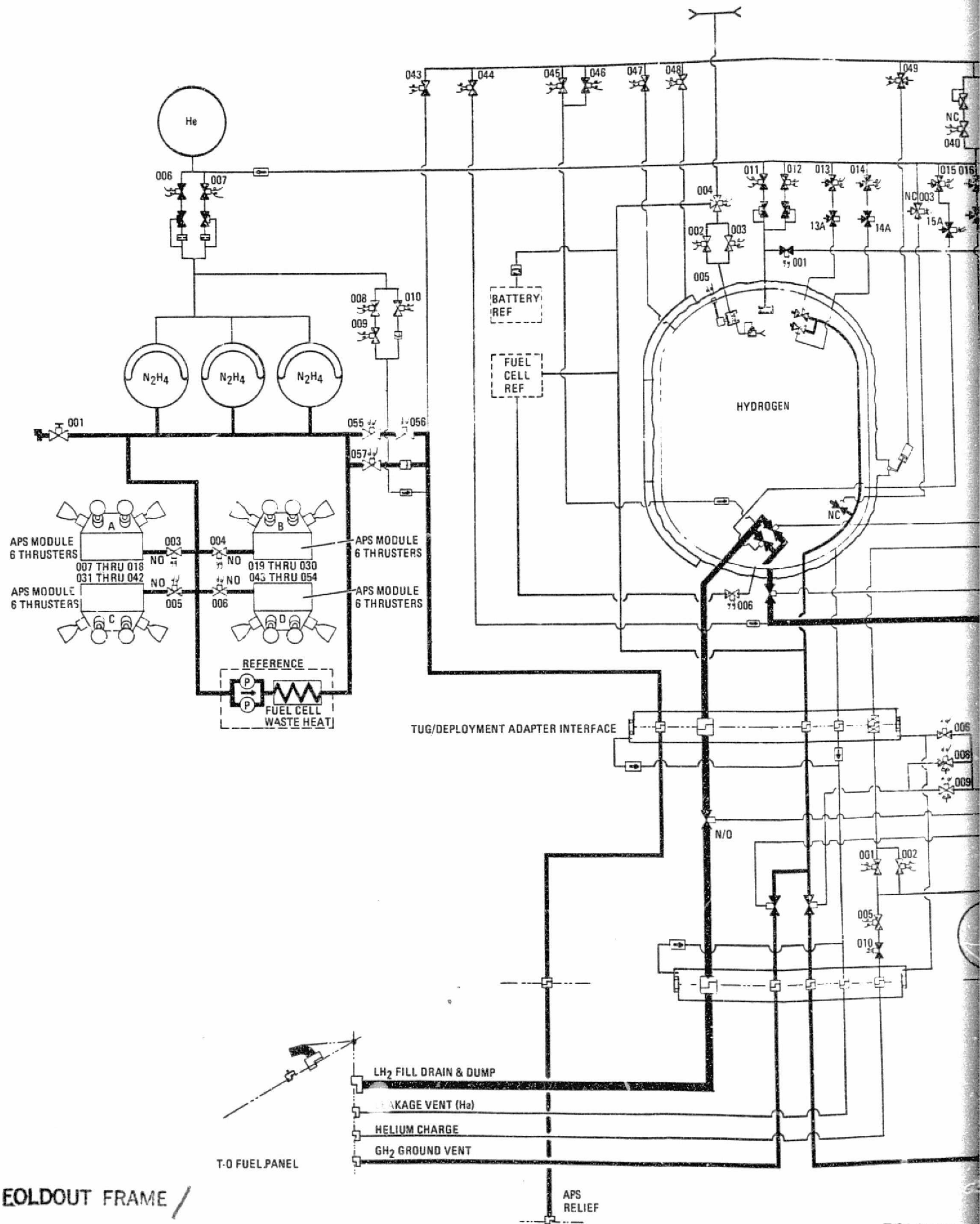
Therefore, it may be possible to design the dump system for orbital dump within the Orbiter thrusting time available, obviating the requirement for aft-directed dump for settling, as discussed in Section 4.4.2.3. Impact of so designing the system was not assessed.

Figure 4.4-32 gives LH_2 dump system flowrate as a function of line diameter and vehicle acceleration. A minimum line diameter of 4.7 inches (11.9 cm) is required for the 300-second RTLS dump. Orbital dump time is 310 seconds.

Tug performance differences for the baseline and mid-body alternatives are negligible. Tug weight is slightly increased since the only significant difference forward of the disconnects is a change from a 3/4-inch (1.9 cm) LO_2 topping line to a 2-inch (5.1 cm) line for fill, drain and topping, increasing weight approximately 20 lb (9.1 kg). Weights in the Orbiter-mounted portions of the line are reduced an estimated 47 lb (21.3 kg) so that payload performance is essentially the same. It was concluded that either the baseline or the mid-body alternative are equally acceptable from the Tug standpoint. The advantages of the mid-body exit appear to be 1) simplification of Orbiter plumbing and interfaces, and 2) possible elimination of the requirement for redirection of dumped propellant for orbital dump settling.

4.4.6 LINE PHYSICAL REQUIREMENTS. Final baseline Tug fluid systems and associated fluid service equipment are shown schematically in Figure 4.4-33. Selection of the basic system arrangement, line sizes, and specification was based on the requirements and trade studies discussed above in conjunction with the additional analyses presented below. Detail design performance requirements at the 1307 panels derived from these trades and analyses are given in Tables 4.4-11 and 4.4-12. The selected diameters given are the diameters of the service lines forward

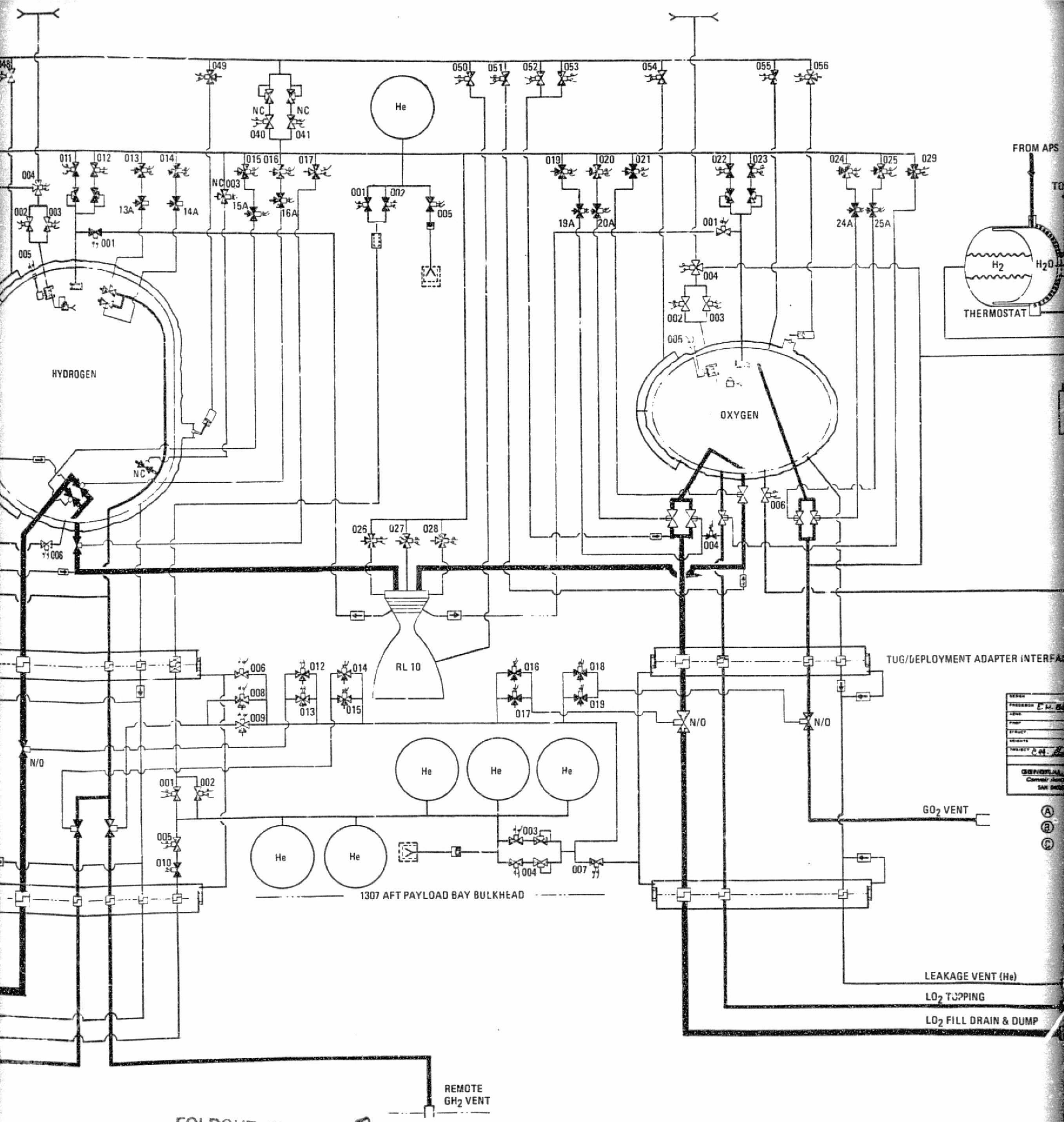
C-5



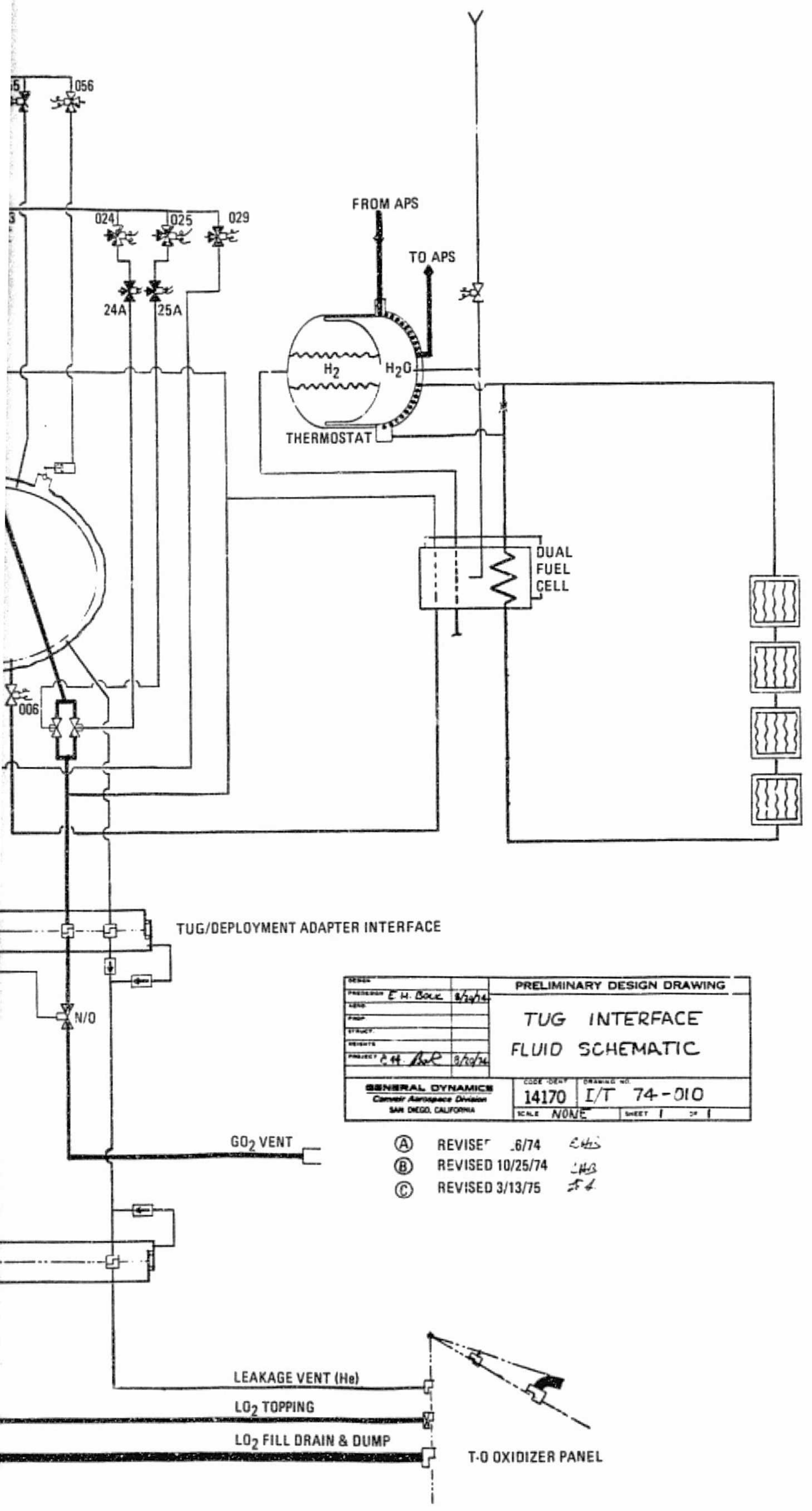
FOLDOUT FRAME /

Figure 4.4-33. Fluid System Schematic

FOLDOUT



FOLDOUT FRAME 2



FOLDOUT FRAME 3

Table 4.4-11. Tug Fluid Interface Requirements at Station 1307, Oxidizer Panel

LO_2 PANEL	DIA. (INCH)		ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (lb-sec)	MAX HEAT LEAK (Btu/hr)	ENVIRONMENT LIMITS INTERFACE				DESIGN CONDITION			
						PRESS (psia)		TEMP (R)		FLOW (lb/sec)	I.F. PRESS (psia)	TEMP (R)	AMBIENT PRESS (psia)
	SELECTED	REQ				MAX	MIN	MAX	MIN				
1. FILL, DRAIN, DUMP	4.0												
a. FILL		2.0	G	5 - 30		28.5	14.7	560	163	24.5	28.5	163.25	14.7
b. DRAIN		2.0	G	30	—	28.5	14.7	560	163	24.5	19.0	163.25	14.7
c. ABORT (RTLS)		4.0	G/AS/O	147	—	26.0	0	560	163	147	18.0	163.25	0
2. LEAKAGE VENT	0.75		ALL										
a. FLANGES													
b. PANEL PURGE													
c. CONTAINMENT				0.008		16	0	560	180	0.008	1.0	180	0.8
3. TOPPING	0.75	0.75	G	0.15-2.0	55	35	0	560	163	2.0	33.6	162.7	14.7
4. HELIUM FILL	0.375	0.30	G	0.022	—	3,200	0	560	500	0.022	200	520	14.7
5. RTG WATER IN	0.5	0.5	G	2		60	0	560	520	2	60	520	14.7
6. RTG WATER OUT	0.5	0.5	G	2		50	0	680	600	2	50	600	14.7
7. RTG STEAM VENT	3.0	3.0	AS, O	0.0135		1.25	0	570	560	0.0135	1.25	560	0

LO_2 PANEL	DIA. (cm)		ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (Kg/sec)	MAX HEAT LEAK (watt)	ENVIRONMENT LIMITS INTERFACE				DESIGN CONDITION			
						PRESS (N/cm^2)		TEMP (K)		FLOW (Kg/sec)	I.F. PRESS (N/cm^2)	TEMP (K)	AMBIENT PRESS (N/cm^2)
	SELECTED	REQ				MAX	MIN	MAX	MIN				
1. FILL, DRAIN, DUMP	10.16												
a. FILL		5.1	G	2.3-13.6	–	19.6	10.1	311	90.5	11.1	19.6	90.7	10.1
b. DRAIN		5.1	G	13.6	–	19.6	10.1	311	90.5	11.1	13.1	90.7	10.1
c. ABORT (RTLS)		10.16	G/AS/O	66.7	–	17.9	0	311	90.5	66.7	12.4	90.7	0
2. LEAKAGE VENT	1.9		ALL										
a. FLANGES													
b. PANEL PURGE													
c. CONTAINMENT				0.0036	–	11.03	0	311	100	0.0036	0.67	100	0.55
3. TOPPING	1.9	1.9	G	0.07-0.09	16.1	24.1	0	311	90.5	0.09	23.2	90.38	10.1
4. HELIUM FILL	0.95	0.76	G	0.01	–	2205	0	311	278	0.01	138	289	10.1
5. RTG WATER IN	1.27	1.27	G	0.9	–	41.4	0	311	289	0.9	41.4	289	10.1
6. RTG WATER OUT	1.27	1.27	G	0.9	–	34.5	0	378	333	0.9	34.5	333	10.1
7. RTG STEAM VENT	7.62	7.62	AS, O	0.006	–	0.86	0	317	311	0.006	0.86	311	0

G = GROUND AS = ASCENT O - ORBIT

Table 4.4-12. Tug Fluid Interface Requirements at Station 1307, Fuel Panel

LH_2 PANEL	DIA (INCH) SELECTED	DIA (INCH) REQ	ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (lb-sec)	MAX HEAT LEAK (Btu/hr)	ENVIRONMENT LIMITS INTERFACE PRESS (psia) MAX	ENVIRONMENT LIMITS INTERFACE PRESS (psia) MIN	ENVIRONMENT LIMITS INTERFACE TEMP (R) MAX	ENVIRONMENT LIMITS INTERFACE TEMP (R) MIN	DESIGN CONDITION FLOW (lb/sec)	DESIGN CONDITION I.F. PRESS (psia)	DESIGN CONDITION TEMP (R)	DESIGN CONDITION AMBIENT PRESS (psia)
8. FILL, DRAIN, DUMP	5.0												
a. FILL		2.0	G	2.0-4.15	—	24	14.7	560	36	4.15	23.5	37.0	14.7
b. DRAIN		2.0	G	4.15	—	24	14.7	560	36	4.15	16.3	37.0	14.7
c. TOPPING		0.75	G	0.15-0.25	350	24	14.7	560	36	0.25	23.5	37.0	14.7
d. ABORT DUMP		5.0	G/AS/0	25	—	24	0	560	36	25.0	17.4	37.0	0
9. TANK VENT	3.0												
PRELAUNCH VENT		3.0	G	0.25	—	23	14.7	560	40	0.25	15.8	60.0	14.7
10. TANK RELIEF	2.5	2.5	AS/0/RE	0.144	—	20	0	560	40	0.144	15.7	75.0	0.25
11. LEAKAGE VENT	0.75		ALL										
a. FLANGES		0.25											
b. PANEL PURGE		0.5											
c. CONTAINMENT		0.75		0.08	—	16.0	0	560	40	0.08	1.0	100	0.8
12. N_2H_4 FILL, DRAIN & RELIEF	0.375	0.375	G	0.05	—					0.05	25.0	520	14.7

LH_2 PANEL	DIA. (cm) SELECTED	DIA. (cm) REQ	ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (Kg/sec)	MAX HEAT LEAK (watts)	ENVIRONMENT LIMITS INTERFACE PRESS (N/cm^2) MAX	ENVIRONMENT LIMITS INTERFACE PRESS (N/cm^2) MIN	ENVIRONMENT LIMITS INTERFACE TEMP (K) MAX	ENVIRONMENT LIMITS INTERFACE TEMP (K) MIN	DESIGN CONDITION FLOW (K/sec)	DESIGN CONDITION I.F. PRESS (N/cm^2)	DESIGN CONDITION TEMP (K)	DESIGN CONDITION AMBIENT PRESS (N/cm^2)
8. FILL, DRAIN, DUMP	12.7												
a. FILL		5.1	G	0.91-1.88	–	16.5	10.1	311	20	1.88	16.2	20.5	10.1
b. DRAIN		5.1	G	1.88	–	16.5	10.1	311	20	1.88	11.2	20.5	10.1
c. TOPPING		1.9	G	0.07-0.11	102	16.5	10.1	311	20	0.11	16.2	20.5	10.1
d. ABORT DUMP		12.7	G/AS/0	11.34	–	16.5	0	311	20	11.34	12.0	20.5	0
9. TANK VENT	7.6												
PRELAUNCH VENT		7.6	G	0.11	–	15.9	10.1	311	22		10.9	33.3	10.1
10. TANK RELIEF	6.4	6.4	AS/0/RE	0.07	–	13.8	0	311	22		10.8	41.7	0.17
11. LEAKAGE VENT	1.9		ALL										
a. FLANGES		0.64											
b. PANEL PURGE		1.3											
c. CONTAINMENT		1.9		0.0036	–	11.03	0	311	22		0.68	55.5	0.55
12. N_2H_4 FILL, DRAIN & RELIEF	0.95	0.95	G	0.023	–	–	0	311	278		17.2	289	10.1

G = GROUND AS = ASCENT O = ORBIT RE = RETURN

of the 1307 panels. The design condition data provided allows determination of Orbiter service line design requirements for compatibility with Tug requirements. This data should be interpreted as follows:

a. Orbiter-to-Tug flow. The Orbiter should provide fluid at flowrate and pressure equal to or greater than specified and a temperature equal to or less than specified.

b. Tug-to-Orbiter flow. The Orbiter should accept fluid at flowrate and temperature equal to or greater than specified at a pressure equal to or less than specified.

All design condition data are for an Orbiter/Tug acceleration of 1.0 g.

4.4.6.1 LO_2 Fill, Drain, and Dump Line. This line is sized by the RTLS abort dump requirement, as discussed in Section 4.4.2.2. The Tug line diameter is 5.0 inches (12.7 cm), including both halves of the disconnect, and the adapter line to the 1307 panel is 4.0 inches (10.2 cm) diameter. Design condition pressures were determined as follows:

Fill

Tank pressure, psia (N/cm^2)	21.0 (14.5) (max design)
Head pressure, psia (N/cm^2)	7.2 (4.96) (full tank)
ΔP (1307 to tank) psia (N/cm^2)	+0.2 (0.14)
Total, psia (N/cm^2)	28.4 (19.6)
Specified, psia (N/cm^2	28.5 (19.65)

Drain

Tank pressure, psia (N/cm^2)	16.0 psi (11) (vapor pressure)
Head pressure, psia (N/cm^2)	+3.5 (2.4) (empty tank)
ΔP, psia (N/cm^2)	-0.2 (0.14)
Total, psia (N/cm^2)	19.3 (13.3)
Specified, psia (N/cm^2)	19.0 (13.1)

Dump

Tank pressure, psia (N/cm^2)	17.0 (11.7) (min regulated during dump)
Head pressure, psia (N/cm^2)	+7.2 (4.96) (full tank)
ΔP, psia (N/cm^2)	-6.2 (4.3)
Total, psia (N/cm^2)	18.1 (12.5)
Specified, psia (N/cm^2)	18.0 (12.4)

4.4.6.2 LO_2 Topping. A small-diameter (3/4 inch) (1.9 cm) vacuum jacketed topping line was added to minimize propellant saturation pressure as discussed in Section 4.4.4. Actual diameter selection was based on a 10 psi (6.9 N/cm^2) maximum pressure loss from the T-0 panel to the Tug tank at the level adjust flowrate of 2.0 lb/sec (0.91 kg (sec). Design condition data specified is at the final level adjust flowrate of 2.0 lb/sec (9.1 kg/sec). Interface pressure required was determined as follows:

Tank pressure, psia (N/cm^2	21.0 (14.5) (max design)
Head pressure, psia (N/cm^2)	7.2 (4.96) (full tank)
ΔP, psia (N/cm^2)	3.9 (2.7) (1307 to tank)
Total, psia (N/cm^2)	32.1 (22.1)
Specified, psia (N/cm^2)	32.0 (22.1)

Maximum heat leak and temperature specified are compatible with the following assumptions:

a. Vapor pressure at T-0 panel: 15.0 psia (10.3 N/cm^2)

b. Vapor pressure of LO_2 topping flow arriving at Tug Tank: 15.5 psia (10.7 N/cm^2).

4.4.6.3 GO_2 Vent. The GO_2 vent line exits the Orbiter through the mid-body. Since it does not pass through the 1307 interface panels, data for the line is not given in Table 4.4-9. The primary design requirement for the line was a maximum ΔP of 0.5 psi (0.35 N/cm^2) at the maximum boiloff rate of 0.2 lb/sec (0.09 kg/sec) for compatibility with the tank saturation/ullage pressure of 15.5 psia (10.7 N/cm^2). Selected line diameter is 2.0 inches (5.08 cu), resulting in a ΔP of 0.15 psi (0.1 N/cm^2) at the design condition.

4.4.6.4 <u>LH_2 Fill, Drain, Dump, and Topping</u>. A single common line was selected for all of these functions, as discussed in Section 4.4.4. The line diameter selected to satisfy the abort dump requirement is 4.0 inches (10.2 cm), as discussed in Section 4.4.2.2, from the 1307 panel to the Tug tank. Design condition data pressures were determined as follows:

<u>Fill and Topping</u>

Tank pressure, psia (N/cm^2)	22.5 (15.5) (max design)
Head pressure, psia (N/cm^2	0.9 (0.62) (full tank)
ΔP, psia (N/cm^2)	0.07 (0.05) (negligible topping)
Total, psia (N/cm^2)	23.47 (16.2)
Specified, psia (N/cm^2)	23.5 (16.2)

<u>Drain</u>

Tank pressure, psia (N/cm^2)	16.0 (11.03) (vapor pressure)
Head pressure, psia (N/cm^2)	+0.45 (0.31) (tank empty)
ΔP, psia (N/cm^2)	-0.07 (0.05)
Total, psia (N/cm^2)	16.38 (11.29)
Specified, psia (N/cm^2)	16.3 (11.24)

<u>Dump</u>

Tank pressure, psia (N/cm^2)	18.5 (12.75) (min regulated during dump)
Head pressure, psia (N/cm^2)	+0.9 (0.62) (tank full)
ΔP, psia (N/cm^2)	-2.54 (1.75)
Total, psia (N/cm^2)	16.86 (11.62)
Specified, psia (N/cm^2)	17.0 (11.72)

Maximum heat leak and temperature specified are compatible with the following assumptions:

a. Vapor pressure at T-0 panel during topping: 15.0 psia (10.3 N/cm^2)

b. Vapor pressure of LH_2 topping flow arriving at Tug tank: 16.0 psia (11.03 N/cm^2)

4.4.6.5 LH$_2$ Tank Vent. This vent exits the vehicle through a connection at the T-0 panel to ground disposal facilities. The primary design requirement was for a pressure drop of 0.5 psi (0.34 N/cm^2) maximum at the maximum boiloff rate of 0.25 lb/sec (0.11 kg/sec), for compatibility with a tank saturation pressure of 16.0 (11.03 N/cm^2). T-0 interface pressure assumed was 15.0 (10.3 N/cm^2). The selected line diameter results in a maximum ΔP from Tug tank to the T-0 panel of 0.3 psi (0.2 N/cm^2) and a calculated exit Mach no. of 0.06. The 1307 interface pressure specified was determined as follows:

Tank pressure, psia (N/cm^2)	16.0 (11.03) (saturation pressure)
ΔP, psia (N/cm^2)	0.2 (0.14)
Total specified, psia (N/cm^2)	15.8 (10.9)

4.4.6.6 LH$_2$ Tank Relief. This line vents the tank at all times after launch. It was assumed to exit the Orbiter through the top of the vertical tail. A line diameter of 2.5 inches (6.35 cm) was selected. If this diameter is maintained to the vertical tail exit, maximum ΔP is 1.0 psi (0.67 N/cm^2) at a flowrate of 0.22 lb/sec (0.1 kg/sec), twice the predicted steady-state boiloff rate for an aborted flight landing with a full LH$_2$ tank. This presumes a failure of the abort dump system. ΔP at twice the maximum predicted flight boiloff rate is 0.4 psi (0.28 N/cm^2). Interface pressure for the flight vent case was determined as follows:

Tank pressure, psia (N/cm^2)	16.0 (11.03) (saturation-pressure)
ΔP, psia (N/cm^2)	0.22 (1.5) (tank to 1307 panel)
Total, psia (N/cm^2)	15.78 (10.9)
Specified, psia (N/cm^2)	15.7 (10.8)

4.4.6.7 Leakage Vents. These lines collect all leakage and conduct it to the T-0 panels for disposal. The condition that sizes the vent lines is vent-down of the leakage containment membrane during ascent as the payload bay pressure drops rapidly. To limit the maximum ΔP across the membranes to 0.1 (0.7 N/cm^2) a diameter of 0.75 inch (1.9 cm) was required for both the LH2 and the LO2 membranes. The maximum ΔP occurs 80 seconds after launch where the ambient pressure is 0.8 psia (0.55 N/cm^2).

4.4.6.8 Helium Fill. This line provides for charging and discharging the helium storage bottles in both the Tug and the Tug deployment adapter. Quantities are as follows:

Adapter:	61 lb (27.7 kg)
Tug:	20 lb (9.1 kg)

For an assumed one-hour charge time requirement, a flow rate of 0.022 lb/sec (0.01 kg/sec) is required. For the 3/8 (0.95 cm) tubing selected, pressure loss during charging at the one-hour rate is 2.5 (1.7 N/cm^2) allowing adequate margin for higher rate charging if desired.

4.4.6.9 Hydrazine Relief. This line provides N_2H_4 dump capability to relieve ΔP bottle overpressure due to N_2H_4 decomposition. At the nominal tank pressure of 300 (206 N/cm^2) the entire load of N_2H_4 could be dumped in 1.5 minutes through the selected 3/8 inch (0.95 cm) line through a connection at the T-0 panel. The design condition data shown is for this condition.

4.5 ENVIRONMENTAL INTERFACE

The Tug and its payload must be capable of surviving in the environment of the payload bay; conversely, the Tug must not produce an environmental condition that can adversely effect the Orbiter or payload. This subtask assessed the environmental interface using the NASA-supplied baseline Tug and payload environmental requirements from the IUS/Tug Payload Requirements Compatibility Study. Thermal, contamination, and acoustic environments were considered. Trade studies were conducted to establish compatible ground conditioning specifications and Orbiter payload bay conditioning control requirements for baseline Tug. Special emphasis was placed on analyzing potential contamination sources and determining their effect on the Space Tug/ Spacecraft.

4.5.1 THERMAL CONTROL. The most significant thermal control interface consideration for the Tug in the Orbiter payload bay involved the prelaunch conditioning of the Tug and spacecraft to provide an acceptable thermal environment. The operational conditioning gas temperature and flow envelope was defined, which was compatible with both Tug and spacecraft requirements. The Tug mounting-point worst-case temperature conditions were also established for all the separate modes of vehicle operation. It was found that no Tug design impact was caused by mounting-point temperature extremes.

4.5.1.1 Prelaunch Conditioning. The analysis of prelaunch conditioning requirements in the Orbiter payload bay was begun with a review of the SSPD data (Reference 4.5-1) to determine the temperature limit extremes required for each spacecraft when mated to Tug. The data on Figure 4.5-1 show the all-inclusive temperature band for the spacecraft limit temperatures to be between 59F and 69F (288K and 294K) in the worst case for four of the 50 payloads. This band is acceptable for all SSPD Tug payloads, and for simplicity can be specified for temperature control of all spacecraft.

The predicted power dissipation characteristics of each payload in the prelaunch mode were determined from the level B SSPD data (Figure 4.5-1). Data are unavailable for approximately half of the spacecraft for prelaunch; however, the maximum power use indicated is 560 watts for payload AS-20-A. A review of total power requirement shows three payloads will use 5000 watts of power when operational (data not available for prelaunch for these spacecraft).

A Tug/spacecraft thermal analysis of the effect of spacecraft power dissipation on nitrogen purge gas heating was conducted to establish the possible effect of self heating on the average spacecraft purge environment. For this purpose a parametric analysis of the worst-case purge gas temperature rise was run as a function of power dissipation and purge flow rate. The data are shown in Figure 4.5-2. The maximum temperature rise for the worst-case prelaunch power dissipation given is only 1.3F (0.7K)

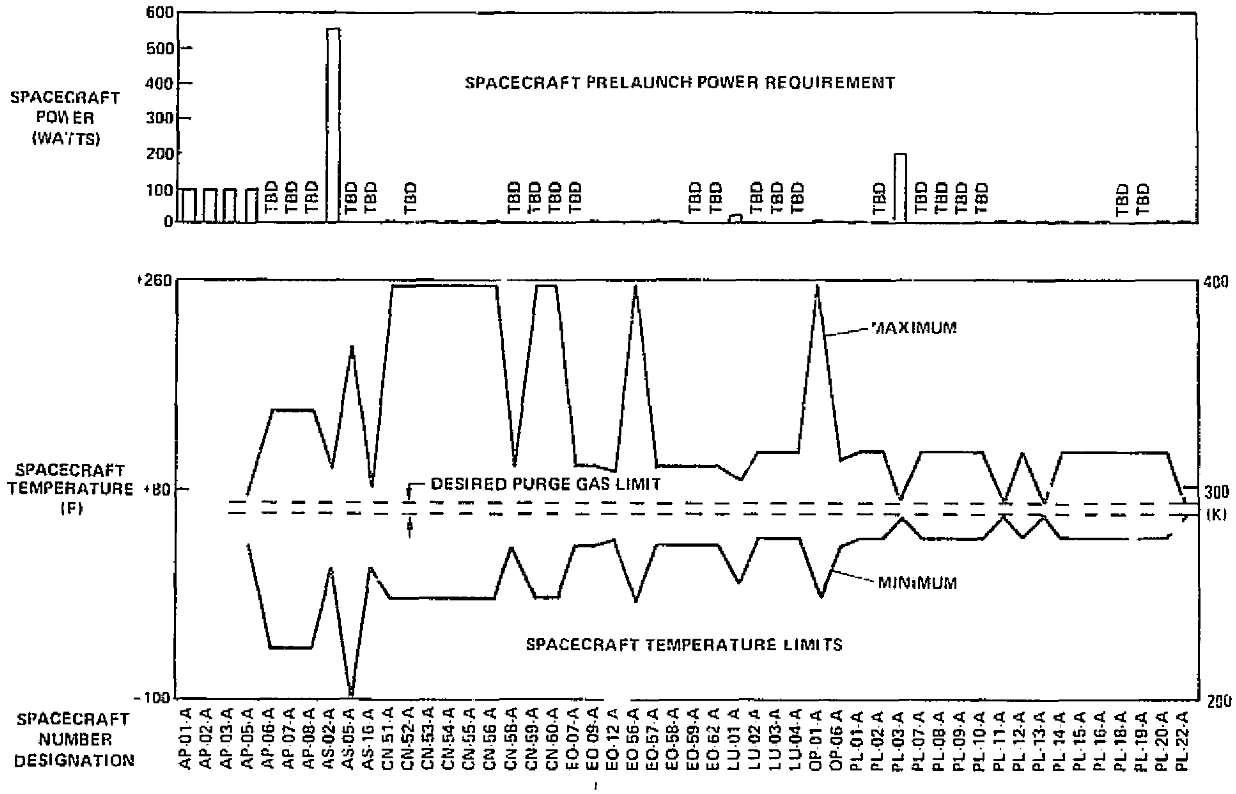


Figure 4.5-1. Spacecraft Prelaunch Power and Temperature Requirements for Tug-Mounted Payloads in Payload Bay

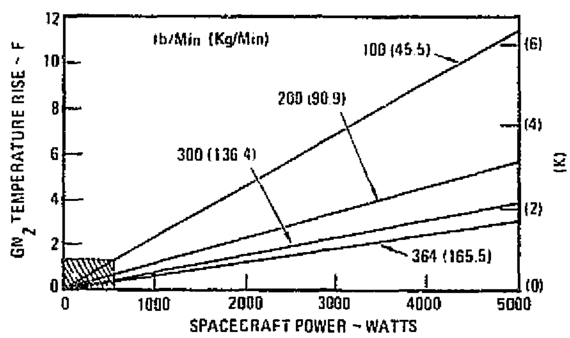


Figure 4.5-2. Purge Gas Temperature Rise Due to Spacecraft Heating

for a purge flow as low as 100 lb/min (45.5 kg/min). This is an insignificant amount, and heating of the purge gas by spacecraft power dissipation can be disregarded.

The major prelaunch conditioning analysis concerned the determination of gaseous nitrogen (GN_2) purging requirements to provide the Space Tug with an acceptable prelaunch environment. In accordance with JSC 07700 (Reference 4.5-2). The Orbiter payload bay GN_2 ground purging capability is:

Flow, lb/min (kg/min)	0-364 (0-165.5)
Temperature, F (K)	45-120 (280.6-322.2)
Humidity	0-1 grain H_2O/lb N_2 (0-0.14 gm H_2O/kg N_2)

The configuration of the Orbiter purge distribution system is shown in Figure 4.5-3.

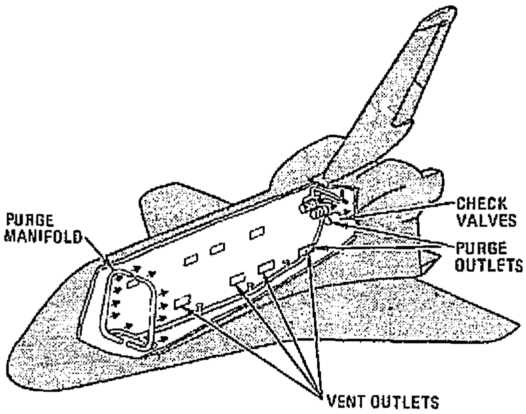


Figure 4.5-3. Orbiter Ground Purge Distribution System

The Space Tug is oriented in the aft portion of the payload bay, facing forward, with the spacecraft mounted to the end of Tug located nearest the purge manifold. The present configuration of the purge distribution system contains a main purge manifold plus three optional stub outlets from the main distribution line. For the analysis conducted in this study, the optional stub outlets were not used. As the detailed thermal characteristics of Tug subsystems become defined, it may be necessary to use conditioning flow from one or more of the stub outlets to satisfy specified hardware conditioning requirements.

An evenly distributed purge flow was assumed around the annulus between the Tug and payload bay liner. GN_2 purge gas flowed from the purge manifold to the aft portion of the payload bay. The design of the purge outlets was such that flow up to 115 lb/min (52.3 kg/min) left the payload bay through check valves at the aft bulkhead. All flow greater than 115 lb/min (52.3 kg/min) left the bay through the sidewall vents at Station 1128. The heat transfer characteristics of the propellant tanks during ground hold conditions were extrapolated from actual test data obtained by General Dynamics Convair (Reference 4.5-3) on a test configuration nearly identical to that of Space Tug baseline (Reference 4.5-4).

The Tug prelaunch conditioning analysis was conducted parametrically to define the temperature drop of the GN_2 purge gas and the Tug shell as a function of purge flow rate and temperature. The purge gas temperature drop was calculated by performing an iterative nodal energy balance on the flow stream and propellant tanks. The Tug shell minimum temperature was determined for fully developed turbulent flow using Colburn's equation to establish the local heat transfer coefficient. The results of the study are shown in Figures 4.5-4 through 4.5-6. The exit temperature of the nitrogen purge gas is a function of both the initial gas temperature and flow rate. For a nominal initial gas temperature of 70F (294K) and the maximum flow rate of 364 lb/min (165.4 kg/min), the exhaust gas temperature is 45F (279.4K) at the Station 1128 vent and 12F (262.2K) at the Station 1307 vent. The minimum Tug shell temperature under the same flow conditions was -33F (237.2K).

Spacecraft requirements were reviewed to determine the parametric constraints to be used in purge gas thermal analyses for Tug conditioning during prelaunch tanking.

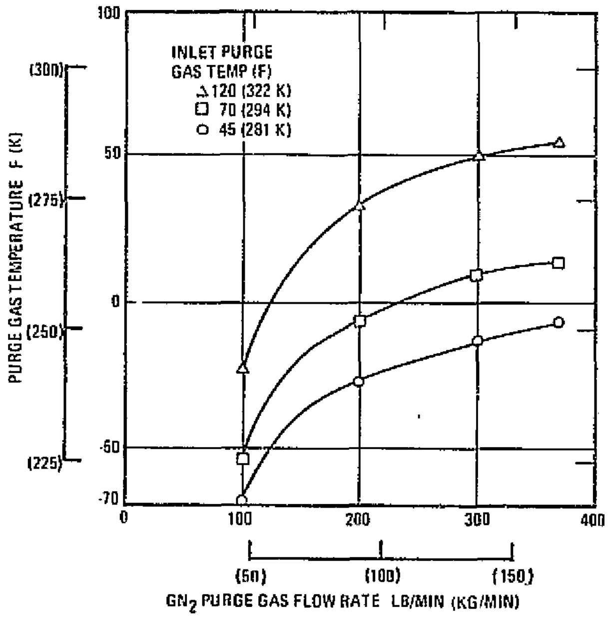


Figure 4. 5-4. GN_2 Purge Gas Temperature at Station 1128 Vent

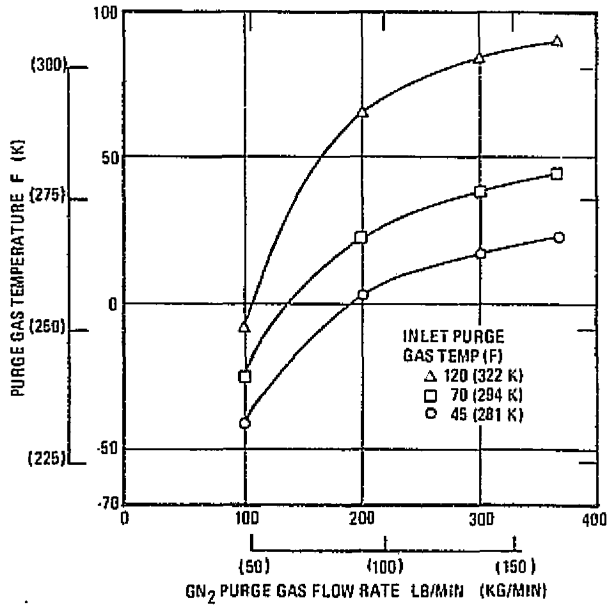


Figure 4. 5-5. GN_2 Purge Gas Temperature at Station 1307 Vent

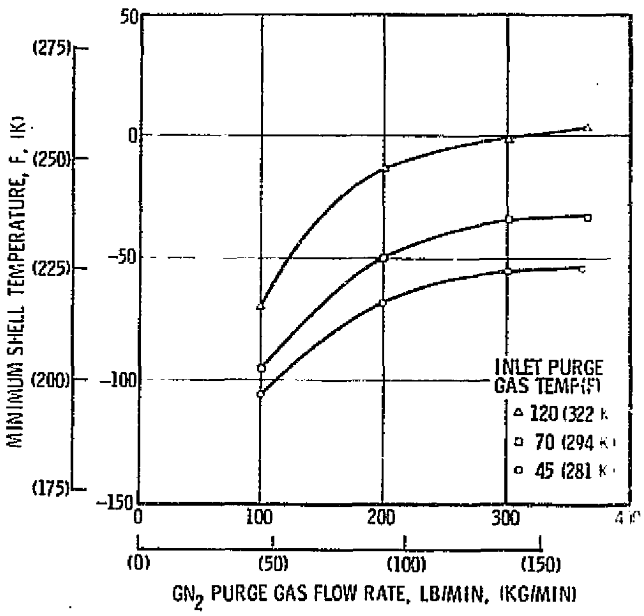


Figure 4. 5-6. Minimum Shell Temperature Tanked During Prelaunch Purge

Temperature and humidity limit requirements were determined from the NASA/MSFC SSPDA document published in July 1974, for the 50 Space Tug payloads. Temperature limit data as previously indicated showed a common max/min temperature limit band between 59F (288K) and 69F (294K), with a maximum relative humidity requirement of 0 percent for some spacecraft and values up to 95 percent for others. No minimum limits were given, i.e., 0 percent relative humidity is apparently acceptable for all spacecraft.

To preclude condensation of moisture on payload bay, purge nitrogen is required with a dewpoint below that of anticipated surface temperatures. As shown in Figure 4. 5-7, a purge rate of 120 to 140 lb per minute (54. 5 to 63. 6 kg/minute) is required for purge nitrogen having a dewpoint of -76F (213K). For gas with a -45F (231K) dewpoint, 230 to 280 lb per minute (104. 5 to 127. 3 kg/minute) flow is

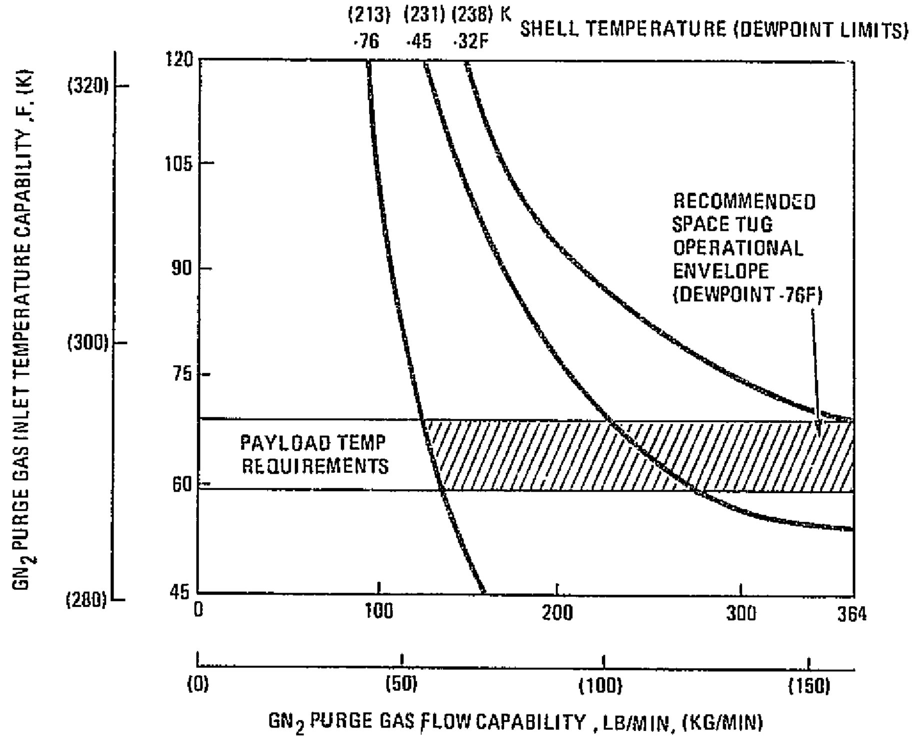


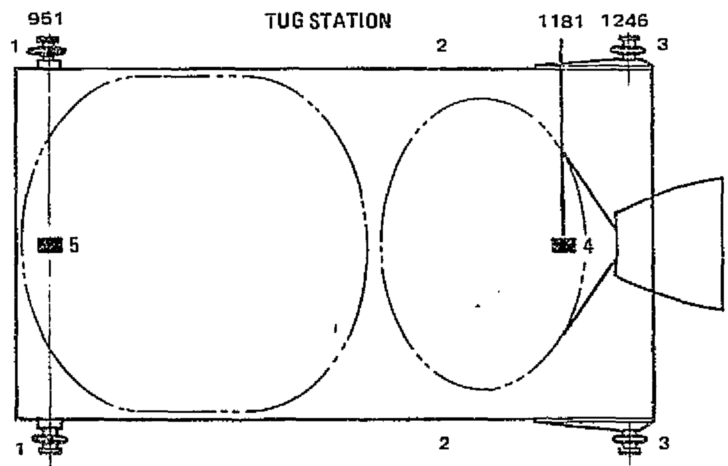
Figure 4.5-7. Prelaunch Conditioning; Maximum Flow Through 1307 Bulkhead is 115 lb/min (52.3 kg/min); Remainder Exhausted Through Side Vents

required, and for gas with a dewpoint as high as -32F (238K), the flow rate requirement is beyond the present Orbiter capability of 364 lb per minute (165.4 kg/minute). Relative humidity for purge gas with dewpoints such as these is, for all intents, 0 percent. and can only be measured in terms of parts per million, grains per lb, or dewpoints in the negative F range. Condensation and frost formation will result if purge gas with anyting over a fractional part of 1 percent relative humidity is used with a cryo upper stage for the prelaunch tanking period.

4.5.1.2 Fitting/Shell Temperatures. Analysis of the maximum and minimum temperature extremes has been made for the Tug/Orbiter attachment fittings and Tug shell for four separate modes of operation: prelaunch, orbit-doors open, orbit-doors clos and entry/landing. The analysis was performed to determine any design impact sed by the predicted fitting temperature extremes.

The Tug plus deployment adapter is attached at two points along each side of the Shuttle cargo bay below the door hinge and at two points on the bottom centerline of the cargo bay. Ground prelaunch attachment fitting temperatures are based on the temperature of the purge GN_2. An on-orbit preconditioning period is planned for Shuttle before entry so that the attachment fittings will not exceed 170F (350K) at

entry and landing. Minimum entry temperatures occur when the Tug returns with the LH_2 tank full, after having been on orbit with the doors closed. The surface $\alpha/\epsilon = 1.0$ and $\epsilon = 0.8$ for a 6-hour fixed attitude and 3-hour barbeque mission profile, respectively. Maximum fitting temperatures with the doors closed are equal to maximum predicted Shuttle structure temperatures with the Tug propellant tanks empty. Minimum fitting temperatures are less than minimum predicted Shuttle structure temperatures when cryogens are in the MLI insulated Tug tanks. The temperature limits of the Tug shell during prelaunch are determined by the GN_2 purging conditions. The inflight limits are established as described above. The location of the Tug primary and alternative (Point 2) mounting attachment fittings is shown in Figure 4.5-8.



MISSION PHASE	MAXIMUM/MINIMUM TEMPERATURES, F (K)					
	1	2	3	4	5	SHELL
PRELAUNCH	120/+45 (322/280)	120/-42 (322/232)	120/-76 (322/213)	120/-42 (322/232)	120/+45 (322/280)	120/-76 (322/213)
ON-ORBIT – DOORS OPEN	250/-85 (394/208)	250/-85 (394/208)	250/-85 (394/208)	106/-165 (314/164)	120/-140 (322/178)	250/-168 (394/162)
ON-ORBIT – DOORS CLOSED	10/-193 (261/148)	37/-184 (276/153)	50/-116 (283/191)	106/-165 (314/164)	120/-140 (322/178)	113/-193 (318/193)
ENTRY AND LANDING	170/-190 (350/149)	170/-181 (350/155)	170/-113 (350/193)	140/-162 (333/166)	140/-137 (333/179)	170/-110 (350/194)

Figure 4.5-8. Attachment Fitting and Shell Temperature Extremes

The Tug shell temperatures were calculated for worst-case extreme conditions on the shell. The predicted maximum and minimum temperature extremes are also shown in Figure 4.5-8. A rather wide variation in fitting and shell temperatures is predicted for the various Orbiter modes of operation. These extremes, particularly the low values, require special attention in the selection of materials for attachment fittings, but generally the materials are well within the present state of the art. The Tug deployment adapter shell is of epoxy graphite composite construction, which is compatible with a very wide range of temperatures. It is recommended that the attachment fitting designs incorporate the use of materials such as titanium and,

possibly, multiphase alloy MP35N, which are compatible with the anticipated low temperature extremes. Detailed definition of the attachment design requirements is contained in Section 4.2.3. Based on the combined thermal and structural analyses, there appears to be no Tug design impact caused by temperature extremes.

4.5.2 CONTAMINATION CONTROL. Ground and flight operational procedures and facilities for the Space Tug and its payload were reviewed to determine potential contamination sources and contamination control requirements. To provide the greatest degree of assurance for mission success from a sensitivity to contamination standpoint, all elements of the space transportation system (STS) must be guarded against the five major types of contaminants: particulates, volatile condensable materials, hydrocarbons, moisture and nonvolatile residue. All, in one way or another, can cause system malfunction, degradation of component life or reliability through corrosion or wear, optical interference, and possible explosion or fire.

4.5.2.1 Ground Operations. During ground operations as depicted by Figure 4.5-9, contamination can occur during transport, handling, maintenance and mating with spacecraft or Orbiter; from ambient or induced environments, dirty surfaces, system venting, leakage, or material outgassing.

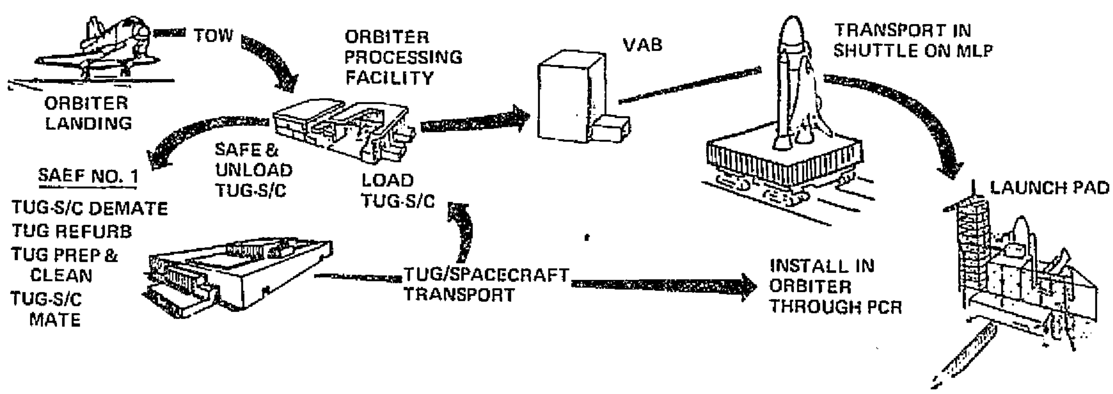


Figure 4.5-9. Typical Space Tug Ground Flow Sequence

Contamination requirements for Tug payloads (spacecraft), obtained from SSPDA documentation, were compared with the various Shuttle user agency requirements. Spacecraft requirements, Table 4.5-1, vary from 100 to 100,000 particles per cubic foot (3531 to 3,531,470 particles/m^3) for the 130 examples shown.

Purity of prelaunch conditioning purge gas is specified in the MSFC, DOD and JSC documents shown in Table 4.5-2, and varies by two orders of magnitude.

Table 4.5-1. Spacecraft Cleanliness Requirements

Requirements		Cleanliness Class, (particles/ft^3) (particles/M^3)
Spacecraft		
Total Quantity From SSPD Data	4	100 (3531)
	6	5,000 (176,573)
	23	10,000 (353,147)
	67	100,000 (3,531,470)
	24	TBD
	6	N/A

Table 4.5-2. Purge Gas Cleanliness

Requirements	Cleanliness Class, (particles/ft^3) (particles/M^3)
Payload Bay	
DOD 7-15-73	100,000 (3,531,470)
MSFC PD 73-1	10,000 (353,147)
JSC 07700	100 Nom 5,000 Guar (3531 Nom 176,373 Guar)
KSC Payload Processing Facility	10,000 (353,147)

Definitions of these cleanliness levels are:

Class 100,000 is a nominal cleanliness level for assembly operations, but is inadequate for maintenance of spacecraft surface cleanliness if the purge is continued for more than an hour or so.

Class 10,000 purge is a good, clean environment, adequate for 92 percent of the spacecraft in the mission model, and is available at existing facilities for vehicle maintenance and refurbishment, and spacecraft mating. (Manned Spacecraft Operations and Checkout Building, MSOB, and the Spacecraft Assembly and Encapsulation Facility, SAEF #1.)

Class 100 purge is a highly controlled, small volume condition necessary for preparation of highly contamination-sensitive spacecraft but is impractical for large maintenance facilities and mating operations.

Contamination can best be controlled through application of three separate and distinct control methods: Design, Controlled Environment Purge, and Surface Cleaning.

Design. All elements of the STS must be designed to minimize outgassing, through use of approved minimum outgassing materials only. To prevent contamination from vehicle system venting and leakage, it is recommended that all tank vents be ducted overboard from the Orbiter, employing purge envelopes to contain such contaminants.

Controlled Environmental Purge. To prevent buildup of surface contamination and maintain existing cleanliness, Class 10,000 environmental purge is recommended for all facilities used during ground operation, for all GSE ground operations, and for the Orbiter payload bay. Class 10,000 is a good, clean environment for 92 percent of the spacecraft in the mission model, and is available at existing KSC facilities for vehicle maintenance and refurbishment, spacecraft mating, and Orbiter mating. To provide maximum confidence in a Class 10,000 environment or better, Class 100 (two orders of magnitude cleaner) air is supplied to the cleanroom facilities noted, including the launch pad payload changeout room.

Surface Cleaning. Cleaning and inspection of all STS elements should be done just before mating, at the completion of maintenance and refurbishment functions for the Orbiter and Tug, and at the completion of flight preps for the spacecraft. Surfaces should be cleaned to a visibly clean, Level 300A condition for compatibility with the Class 10,000 environmental purge. For spacecraft (8 percent) with more stringent cleanliness requirements (Surface level 100 or 10, Purge Class 5000 or 100), the spacecraft sponsor should clean to his own required surface cleanliness level, and spacecraft shrouds or component covers should be provided to maintain cleanliness.

Study recommendations for prelaunch/postlanding contamination control are summarized in Figure 4.5-10.

A special analysis was made of Tug fluid venting sources to determine the extent of potential contamination of the spacecraft environment in the Orbiter cargo bay. All propellant boiloff and tank leakage is captured and ducted overboard, and pose no spacecraft contamination hazard. The major potential fluid contamination source is the helium purge gas used for multilayer insulation (MLI) conditioning before propellant tanking. The helium gas will be vented into the Tug cavity between the propellant tanks. Purging will occur for 15 minutes before propellant tanking, at which time the vent will be closed. From this time until liftoff, the only source of additional helium will be any leakage from the MLI purge bags. During all ground operations when helium is present in the MLI, the cargo bay of the Orbiter will be purged with gaseous

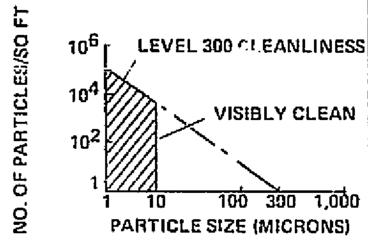
CONTAMINANT	SPECIFICATION SOURCE JSC 07700	MSFC PD-73-1	DOD 7-15-73	RECOMMENDATION
PAYLOAD BAY ENVIR PURGE PARTICULATES VCM HYDROCARBONS HUMIDITY	 100/5,000 — 15 PPM 1 GR/LB	 10,000 2×10^{-9} LB/LB — 11 PPM	 100,000 — -40 DEG F (DP)	 10,000 2×10^{-9} LB/LB 15 PPM 11 PPM
SURFACE CLEANLINESS PARTICULATES NVR	 VISIBLY CLEAN —	 TBD	 LEVEL 300 LEVEL A	
VENTING (TUG & SPACECRAFT)	—	✓	—	GHe & GN_2 INTO BAY, OTHERS OVERBOARD
OUTGASSING	1% MTL LOSS 0.1% VCM	✓	—	USE APPROVED MATERIALS
LEAKAGE				NEGLIGIBLE CONTAMINANT LEAKAGE INTO BAY (PURGE BAGS CONTAIN LEAKAGES & DUCT OVERBOARD)

Figure 4.5-10. Contamination Control Recommendations

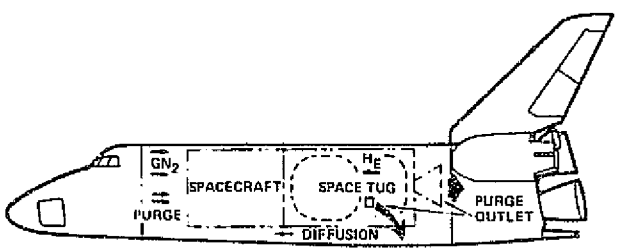


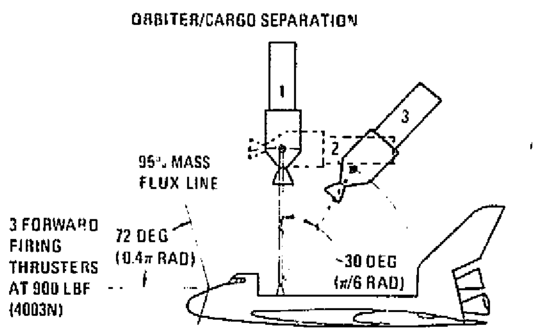
Figure 4.5-11. Model for Analysis of Potential Spacecraft Contamination Due to Space Tug Helium Venting

nitrogen (GN_2). The GN_2 purge will be introduced at the forward end of the cargo bay, flow past the spacecraft and Tug and exit from the aft end of the cargo bay (see Figure 4.5-11). Minimum GN_2 flow rate with the Tug in the cargo bay is 140 lb per minute (63.6 kg/min).

A worst-case static (no GN_2 flow) analysis was performed to determine the maximum possible rate of diffusion of helium from the Tug intertank area to the Tug/spacecraft interface. The rate was established as approximately 0.0005 pound per minute (0.00023 kg/min). It is readily apparent that helium in any significant quantity will not reach the interface with GN_2 purge in operation. During ascent, conditioning gases venting from the spacecraft will also prevent any inflow of the surrounding environment. Therefore, it is concluded that no contamination of the spacecraft environment will be caused by venting of the MLI helium purge gas into the cargo bay.

4.5.2.2 Flight Operations. Inflight contamination can result from a variety of sources including fluids venting, materials outgassing, transfer of contaminants from cargo bay surfaces, and Orbiter APS thruster exhaust impingement. Venting of fluids from the Orbiter and Tug should be directed away from the payload and/or inhibited during periods when contamination potential is highest, such as during deployment and retrieval operations. Outgassing problems can be minimized by proper choice of materials. Maintenance of required cargo bay cleanliness levels and installation of a cargo bay liner to minimize exposed surface areas and contaminant collection points will reduce surface transfer contamination.

Orbiter APS thruster contamination can be held at acceptable levels by use of forward firing thrusters to separate Orbiter from the Tug following RMS release. Exact positioning of the Tug for the separation maneuver is a function of the desired separation distance and time before activating the Tug APS or main propulsion systems. Figure 4.5-12 illustrates the time to achieve one-mile (1609 m) separation by firing three forward-facing 900 lbf (4003N) Orbiter thrusters until the 95 percent flux line intercepts the payload for the three Tug and payload positions illustrated. The minimum separation time is achieved by position 3. Rotation of the payload past the 30 degree ($\pi/6$ rad) position (number 3) to the Z axis is undesirable due to reduced physical clearance with the Orbiter vertical stabilizer. Determination of a minimum safe separation velocity and distance required before activation of Tug APS or main engine ignition is necessary before performing further evaluation of separation techniques.



PAYLOAD POSITION	APPROXIMATE ORBITER SEPARATION VELOCITY	APPROXIMATE TIME TO 1 MILE SEPARATION
1	5.5 FT/SEC (1.68 M/SEC)	16.0 MIN
2	6.5 FT/SEC (1.98 M/SEC)	13.5 MIN
3	8.1 FT/SEC (2.47 M/SEC)	11.0 MIN

Figure 4.5-12. Firing Three 900-lbf (4003N) Thrusters Until 95 Percent Flux Line Intercepts Payload

4.5.3 VIBRATION AND ACOUSTICS. As with all launch vehicles, the Shuttle induces a significant vibration and acoustic environment. This task investigated Tug plus payload dynamic response and compared Orbiter and payload acoustic environments.

A combined Tug/Orbiter/payload structural dynamics analysis was beyond the scope of this study and is not advisable until a more detailed definition of both Tug and Orbiter characteristics become available. However, a preliminary analysis of Tug-forced response characteristics due to the Shuttle liftoff transient was made. The acoustic environmental requirements of tug payloads were compared with the Orbiter conditions. Requirements for additional sound suppression were noted and some preliminary recommendations made.

4.5.3.1 Dynamic Response. Both modal and forced response analyses were conducted on candidate Tug/Orbiter support arrangements (determinate, load balanced, and redundant). The analyses showed that four Z and two Y supports are required to maintain adequate Tug/Orbiter clearance. The details of the analyses are contained in Section 4.2.3 of this report.

4.5.3.2 Acoustic Response. A preliminary evaluation was made of Orbiter payload sensitivity to acoustical noise. The NASA/MSFC payload description document (Reference 4.5-5) was reviewed to determine applicable spacecraft and their acoustic limits in terms of overall sound pressure level. These data with the SSPD payload descriptors are shown in Table 4.5-3. Figure 4.5-13 shows the estimated acoustic environment of the Orbiter payload bay during liftoff. It was determined from Rockwell International (Reference 4.5-6) that aerodynamic noise at maximum dynamic pressure (q) flight conditions would be lower than liftoff noise. Because of its more recent development, the acoustic environment described by Figure 4.5-13 was used for analysis in lieu of that shown in Figure 4-6 of "Space Shuttle System Payload Accommodations," JSC 07700, Volume XIV, Revision C, dated 3 July 1974.

Referring to Table 4.5-3 it was noted that, based on overall sound pressure level, the acoustic limits of 50 of the 78 defined payload items were less than the level of the estimated environment. Furthermore, the acoustic limits of 39 of the 50 items were 6 dB or more (acoustic power ratio of 4) below the environmental acoustic level (Figure 4.5-14). Hence, at this point it was suggested that 50 payload items will require further evaluation with respect to their acoustic limits, and that a significant percentage of the 39 items might require attention from the design and/or installation standpoints. Although tentative warnings have been given of the acoustic sensitivity of 64 percent of the payload items, it was worthwhile to examine the premises upon which the above warnings were based. First, indication of an acoustic limit without definition of an allowable exposure time was meaningless. For example, a payload item with a limit of 142 dB may fail in an 150 dB environment only after exposure for 30 minutes. On the other hand, failure could occur in 1 second. The allowable exposure time of a particular item to the ambient acoustic environment of the orbiter payload bay, therefore, must be considered relative to the required life of the item.

Next, the definition of an acoustic limit in terms of overall sound pressure level, per se, has little significance. For example, the response of an elastic mass (payload item) to a broadband random forcing function (acoustic pressures) becomes significant only at frequencies where there is effective coupling and an efficient transfer of energy to the elastic mass. These frequencies are the resonant frequencies of the elastic mass and only the energy within narrow frequency bands around the resonant frequencies, generally described by the one-half power points, does any useful work. A payload item with an acoustic limit of 140 dB, as described previously, would be considered unacceptable under the present ground rules in a 150-dB environment. However, if this item were sensitive to noise only at a frequency of 4000 Hz, reference

Table 4.5-3. Summarized NASA Payload Description Level A Data

SSPD Payload	Acoustic Limit (dB)	SSPD Payload	Acoustic Limit (dB)	SSPD Payload	Acoustic Limit (dB)
AP-01-A	146	EO-07-A	150	OP-03-A	150
AP-02-A	146	EO-08-A	150	OP-04-A	150
AP-03-A	146	EO-09-A	150	OP-05-A	150
AP-04-A	146	EO-10-A	150	OP-06-A	150
AP-05-A	138	EO-12-A	145	OP-07-A	150
AP-06-A	145	EO-56-A	150	OP-51-A	TBD
AP-07-A	145	EO-57-A	150	PL-01-A	135
AP-08-A	145	EO-58-A	150	PL-02-A	135
AS-01-A	140	EO-59-A	150	PL-03-A	142
AS-02-A	140	EO-61-A	150	PL-07-A	135
AS-03-A	120	EO-62-A	150	PL-08-A	135
AS-05-A	140	HE-01-A	140	PL-09-A	135
AS-07-A	140	HE-03-A	140	PL-10-A	TBD
AS-11-A	140	HE-05-A	140	PL-11-A	142
AS-13-A	120	HE-07-A	140	PL-12-A	135
AS-14-A	120	HE-08-A	151	PL-13-A	142
AS-16-A	142	HE-09-A	151	PL-14-A	135
AS-17-A	140	HE-10-A	140	PL-15-A	135
CN-51-A	150	HE-11-A	140	PL-16-A	135
CN-52-A	150	HE-12-A	142	PL-13-A	135
CN-53-A	150	LS-02-A	148	PL-19-A	135
CN-54-A	150	LU-01-A	135	PL-20-A	135
CN-55-A	150	LU-02-A	135	PL-22-A	142
CN-56-A	150	LU-03-A	135	SO-02-A	140
CN-58-A	150	LU-04-A	135	SO-03-A	TBD
CN-59-A	150	OP-01-A	150	SP-01-A	145
CN-60-A	150	OP-02-A	150	ST-01-A	145

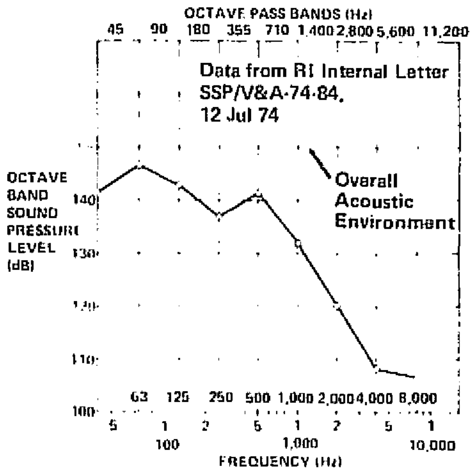


Figure 4. 5-13. Estimated Orbiter Payload Bay Acoustic Environment at Liftoff

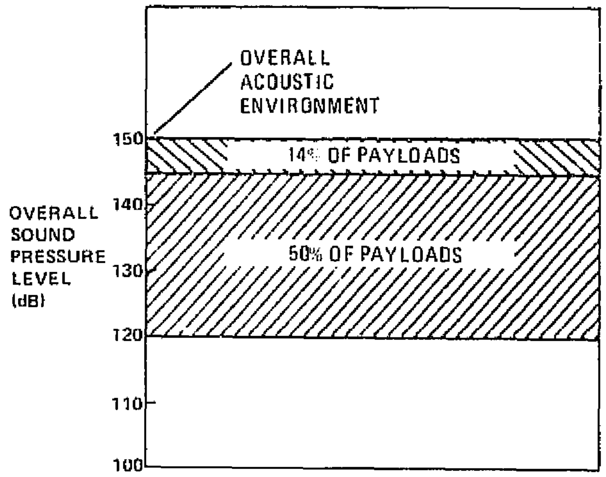


Figure 4. 5-14. Payload Acoustic Limit

to Figure 4. 5-13 shows by inspection that there would be no problem. However, if the sensitivity were at 63 Hz, there could very well be a problem. Thus, to define the acoustic limit of a payload item, the spectral characteristics of its noise sensitivity must be compared with the spectral distribution of the noise field in the payload bay of the orbiter. Time of exposure at resonance then becomes a meaningful parameter upon which to base an evaluation.

An evaluation was made of the estimate of the acoustical environment in the payload bay of the Orbiter. The procedure in estimating the acoustical environment was to subtract the estimated acoustic attenuation of the payload bay structural enclosure from the estimated external sound pressure levels (Reference 4. 5-7). Based on past experience, including a comprehensive and detailed review of the repeatability of actual noise measurements on launch vehicles at liftoff, it was considered that the reliability of estimated external sound pressure levels at liftoff is no better than ±5 dB (Reference 4. 5-8).

The analysis of interior noise levels by RI (Reference 4. 5-9) was straightforward, and it was freely noted that there were areas that are questionable due to as-yet unresolved problems; e.g., the final design of the cargo bay doors, which involves the radiator configuration. The following comments are in no way to be construed as criticisms, but merely relate to some details of the analysis that could influence the results to a significant degree. The assumption of a +6 dB per octave mass law transmission loss (TL) above resonance applies to a plane wave at normal incidence and is highly optimistic. Extensive Convair test data on a wide variety of structural panels indicates that for random incidence a +4 dB per octave TL is more realistic. The assumed TL of -6 dB per octave below resonance is theoretical and largely unsubstantiated. Below

resonance, in the stiffness controlled regime of the cargo bay structure, the volume stiffness of the enclosure has a significant effect on the acoustic transmission loss and could establish a limiting value. It was assumed that the cargo bay was empty. This provides highly diffuse conditions, which will exist only at high frequencies when a large payload volume is carried in the bay. A more precise noise reduction analysis should consider characteristic dimensions of the residual cargo bay volume, with a payload installed, relative to acoustic wavelengths. In conclusion, based on presently available information, it appears premature to penalize either payload items or the cargo bay structure to achieve compatibility between them from the acoustical standpoint.

It is recommended that more detailed data be developed for questionable payload items. The acoustic analysis of the payload bay must be refined and structural transmission loss test data be obtained for representative elements of the payload bay enclosure. Noise reduction measurements should be made on a full-scale payload bay enclosure with a dummy payload installed and the acoustic compatibility of payload items reevaluated.

4.5.4 REFERENCES

4.5-1. Payload Descriptions, Volume 1 Automated Payloads, Level B Data, NASA/MSFC July 1974

4.5-2. Space Shuttle System Payload Accommodations, Level II, Program Definition and Requirements, JSC 07700 Volume XIV, Revision C, July 3, 1974

4.5-3. Walburn, A.B., Leonhard, K. E., and Bennett, F. O., Reusable Multilayer Insulation Research, General Dynamics Convair CASD-ERR-73-033, December 1973

4.5-4. Baseline Space Tug-Configuration Definition, MSFC 68M00039-2, June 28, 1974

4.5-5. Summarized NASA Payload Descriptions, Automated Payloads Level A Data, NASA/MSFC July 1974

4.5-6. RI Internal Letter SSP/V&A-74-84, 12 July 1974

4.5-7. Telecon between Mr. Clay Stevens of Rockwell International Space Division and Mr. Gordon Getline of General Dynamics Convair Division, 4 November 1974

4.5-8. Improved Accuracy of Sonic Fatigue Prediction Procedures for Hypersonic Vehicles, General Dynamics Convair Report GDCA-ERR-1646, December 1971

4.5-9. RI Internal Letter SSP/V&A-74-15, 11 April 1974

4.6 AVIONICS INTERFACES

Avionics interfaces between Tug and its operating environment are of both a functional and physical nature and consist of 1) hardwired interfaces between the Tug vehicle, its deployment adapter, the Orbiter, ground operations, and the Tug payload; and 2) RF communication links interfacing the Tug with Orbiter and ground equipment when the Tug is deployed from the Orbiter. These interfaces are identified in Figure 4.6-1.

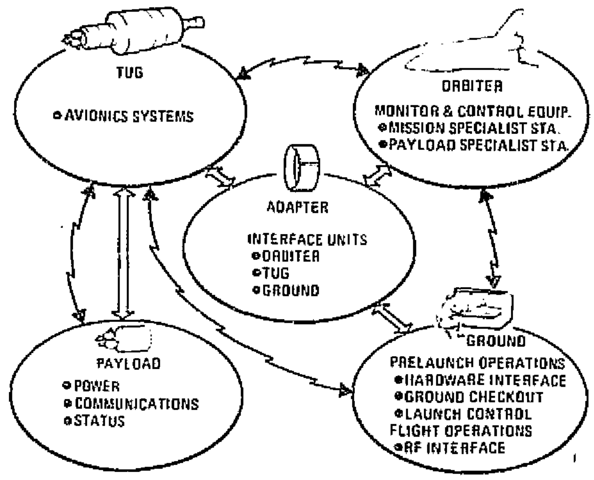
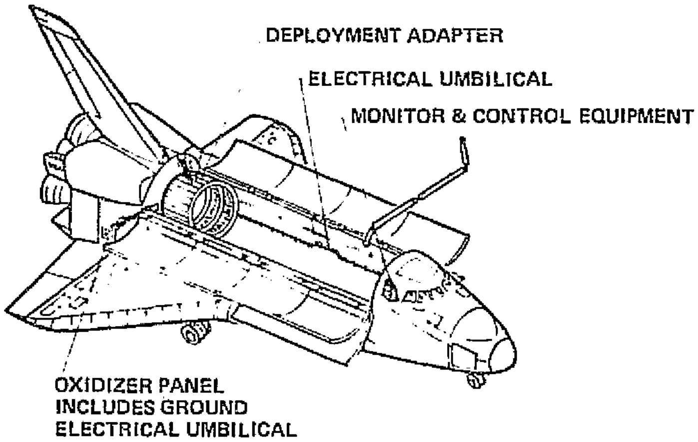


Figure 4.6-1. Tug/Orbiter/Ground Avionics Interfaces

The avionics task was concerned with implementing avionics interface requirements, as contrasted to definition of interface requirements supplied from other studies. Each avionics interface is integrated with and directly involved in Tug management, control, and monitoring of structural, mechanical, fluid, and thermal operations, as well as the Tug avionics system itself. Although the actual physical interfaces (size, location of wires) are necessary to define total system interface requirements, the more fundamental question was concerned with selection of the monitor and control implementation technique and the equipment allocation to accomplish it, which was defined during this task.

The avionics interface task consisted of first defining how much Orbiter monitor and control capability should be supplied by Orbiter-supplied equipment versus Tug-unique equipment. Once this determination was made, the Orbiter crew stations were evaluated for the implementation and allocation of the interface requirements. An assessment was then made of Tug/Orbiter crew man-machine interface effectivity, and Tug/payload electrical power requirements imposed on the Orbiter were identified and evaluated. Finally, an assessment was made of Orbiter cargo bay electrical and service panels (Figure 4.6-2).

To determine Orbiter capability, two basic questions must be considered: "What equipment is available in the Orbiter? and "Will it always be available to the Tug when needed?" A third key issue or question that must also be considered is, "If the Tug requires equipment applicable to a large class of other type payloads, but such equipment is not presently available in the Orbiter, would it be advantageous for the Shuttle to provide it?"



MONITOR & CONTROL ALLOCATION
- ORBITER SUPPLIED
- TUG SUPPLIED

CREW STATION EQUIPMENT/FUNCTION ALLOCATION
- MISSION SPECIALIST STATION
- PAYLOAD SPECIALIST STATION
- CWA PANELS

EFFECTIVITY/MAN-MACHINE INTERFACE
- CONCEPT VALIDITY
- MANUAL VS AUTOMATED CONTROL

TUG/PAYLOAD POWER REQUIREMENTS
- PEAK & AVERAGE
- CONDITIONING

SERVICE PANEL LOCATIONS
- ACCESSIBILITY
- ALTERNATIVE RECOMMENDATIONS

EQUIPMENT REQUIRED
- CRT & KEYBOARD
- PROCESSOR
- CWA & CONTROL PANELS
- 28 VDC POWER
- CONTROL & MONITOR COMMUNICATIONS
- PAYLOAD BAY SENSORS/INDICATORS

Figure 4.6-2. Tug Avionics Interfaces

The latest definitions of Tug requirements and Orbiter equipment were evaluated throughout the study to define the available options of a hardware and software interface implementation split between Orbiter and Tug. Factors evaluated during the study that influenced these decisions are shown in Table 4.6-1.

Output of this task is a recommended technique for Tug/Orbiter interface implementation with an identification of Tug-unique equipment and Orbiter-supplied equipment. In addition, any significant interface benefits realized by changes to Orbiter equipment were identified through Level II change requests. Information resulting from this task includes a specification for each major piece of Tug unique equipment, expressed in terms of number of wires, wire type, shielding requirements, size, routing, grounding provisions, power requirements, cooling, weight, and mounting criteria. Costs of each piece of equipment were estimated and included in Vol. IV. In addition, input/output requirements of the interface equipment were identified based on functional requirements as shown in Table 4.6-2.

4.6.1 AVIONIC FUNCTIONAL INTERFACE DEFINITION. Tug control and monitor data flow requirements were assessed as a function of Tug/Orbiter mission phase to determine the Tug-Orbiter interface implementation requirements. Redundant paths were provided as necessary to meet safety needs, enhance mission reliability, or provide operational flexibility. The resulting interface data paths are tabulated in Table 4.6-3.

This table indicates that four types of operational phases are important for Tug/Orbiter operations:

a. Prelaunch.

b. Ascent/descent.

c. On-orbit attached.

d. On-orbit detached.

These involve five types of interfaces:

a. Safety critical.

b. Abort control.

c. Ground communications.

d. Power.

e. Normal control and monitor operations.

Table 4.6-1. Tug/Orbiter Hardware/Software Allocation Factors

Equipment dedication requirements as a function of Tug/Orbiter operational phase. Example: use of critical Orbiter-supplied Tug support equipment could not be restricted during Tug abort operations.
Capability of existing Orbiter-supplied support equipment.
Software interface requirements in terms of operating speed, core memory requirements, language requirements, mass data storage requirements, etc.
Software development and procedural requirements with respect to software time sharing, checkout, validation.
Interface equipment physical and functional requirements.
Tug vehicle autonomy level and sophisitication in terms of built-in test equipment and onboard checkout capability. *
Special requirements reflecting USAF or payload operations such as communication security. *

*Evaluated as part of Sensitivity Analysis (Section 5).

Table 4.6-2. Functional Requirements

Signal Function	Hardwire safety monitors Hardwired backup control discretes Flight Initialization Control Tug vehicle valve & function control Power change control & monitor Arm/Safe control & monitor Multiplex downlink control & data Electrical Power
Signal Type	Analog Digital Discrete RF Power
Data Transfer Requirements	Data rate Synchronization Modulation Interface impedance, voltage, current Processing rates Error rates Security provisions
Communication Formats	PCM Digital command/monitoring RF command decoding

Interface Implementation Requirements. Safety critical interfaces communicate safety monitor data from the Tug, spacecraft, and deployment adapter to Orbiter and/or ground personnel. These interfaces, which convey caution and warning signal data, must be redundant and operational during all Tug/Orbiter mission phases from prelaunch through landing when the Tug is attached to or in near vicinity of the Orbiter.

Abort control interfaces are concerned with the execution, control, and monitoring of Tug abort operations. Because of the abort interface criticality, it must be redundant. and operationally active during all flight mission phases where the Tug is attached to the Orbiter. It is also a requirement that safeguards be implemented to prevent inadvertent execution of abort operations by any single anomalous crew action of interface equipment failure.

Two categories of ground communication interfaces are required for Tug/Orbiter operations. The first category consists of hardwired interfaces required for prelaunch

Table 4.6-3. Tug/Orbiter/Ground Interface Implementation

Phase	Function	Backup Requirement*	Primary Path Up	Primary Path Down	Backup Path Up	Backup Path Down	Comments
Prelaunch	Safety Critical	S	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	Operational B/U via gnd RF/PSP link
	Operations	O	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	TLM via Orbiter is alternative (RF or umbilical)
	Power	S	Orb Sta 695 Ded Fuel Cell	-	Orb Sta 695 Main Bus	-	Deployment adapter power through Orb Sta 1307
Ascent	Safety Critical	S	PSP - GPC No. 1	C&W to MSS TLM - PSP	PSP - GPC No. 2	TLM - PSP No. 2	
	Abort	S	PSP to DMS	TLM via PSP	PSP to CIU & D/A IU	PSP No. 2	Operational B/U via gnd RF/PSP
	Ground Comm	C	PSP	PSP	PSP 2	PSP 2	
	Power	S	Tug Fuel Cells (2)	-	Orb Sta 695	-	Deployment adapter power through Orb Sta 1307
On-Orbit Attached	Safety Critical Abort Ground Comm Power	Same as ascent					
	Operations	O	PSP - DMS PSP-C/O from Gnd	PSP to GPS PSP to Gnd	PSP 2 TO DMS	PSP 2 TO Gnd	
On-Orbit Detached	Safety Critical	S	PI	PI	PI 2	PI 2	Arm/Safing & loiter RF commands
	Operations	R	Gnd Net	Gnd Net	Gnd Net 2	Gnd Net 2	PI is backup for less than 20 miles

*S = Safety
R = Mission Reliability
C = See comments
O = Operational Convenience

operations. It is a Tug baseline requirement that a Tug/ground interface be provided to allow uplink/downlink communication (with LPS) without requiring the Orbiter's avionic systems to be activated. Two important points concerning Tug/ground interfaces are: 1) Tug/Orbiter interface through the Orbiter's payload support equipment permits Tug/ground communication through the normal Orbiter/ground hardwired and RF interface paths, and 2) GSE power will be supplied to Tug and spacecraft functions during prelaunch operations through the Orbiter power distribution system (using the same interfaces that are available to payloads during flight operations).

Tug, spacecraft, deployment adapter, and aft crew station equipment functions will require electrical power from the Orbiter during the various Tug/Orbiter mission phases. The associated power interfaces will be required to reflect Orbiter power requirement such as:

a. Limited Orbiter power availability during certain mission phases.

b. Maintaining separation of Orbiter current from separate Orbiter fuel cells.

c. Use of Orbiter multiple-point ground philosophy.

The final class of interfaces includes all of the interface functions required for normal prelaunch and flight operations. These interfaces must allow reliable control and monitoring of operational functions such as:

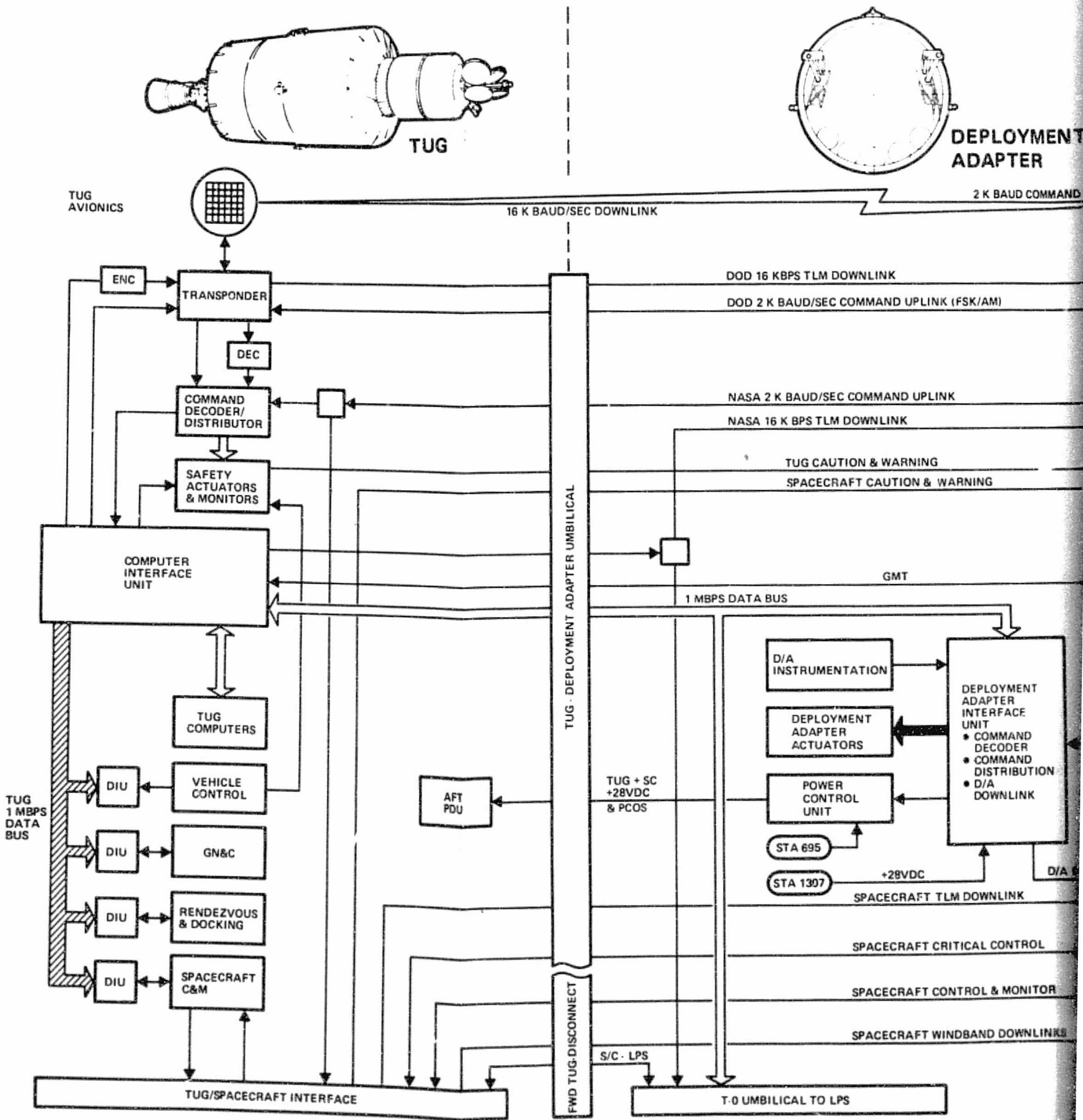
a. Propellant tanking and Tug DMS update (prelaunch)

b. Deployment adapter control during Tug deployment/retrieval operations.

Other interfaces of this nature involve the transfer of data to the Tug (such as GN&C update parameters and time reference data).

Avionics Interface Block Diagrams. The recommended Tug/deployment adapter to Orbiter interface implementation is indicated in the block diagram of Figure 4.6-3 for NASA and DOD payloads, ground and flight operations, and flight attached and detached operations. The major functional units associated with this interface consist of the Tug avionics (transponder, command decoder, and computer interface unit), deployment adapter interface avionics, and Orbiter avionics and man-machine interfaces.

Major electronics elements associated with the Tug deployment adapter include the deployment adapter interface unit, valves and actuators associated with the control of propellants, fluids and gases; deployment interface hardware, instrumentation, and the deployment adapter power control unit. The deployment adapter interface unit includes a command decoder, command distributor, and a downlink data multiplexer unit (PCM TLM).



FOLDOUT FRAME 1

Figure 4.6-3. Tug/Orbiter Interface

FOLDOUT FRAME 2

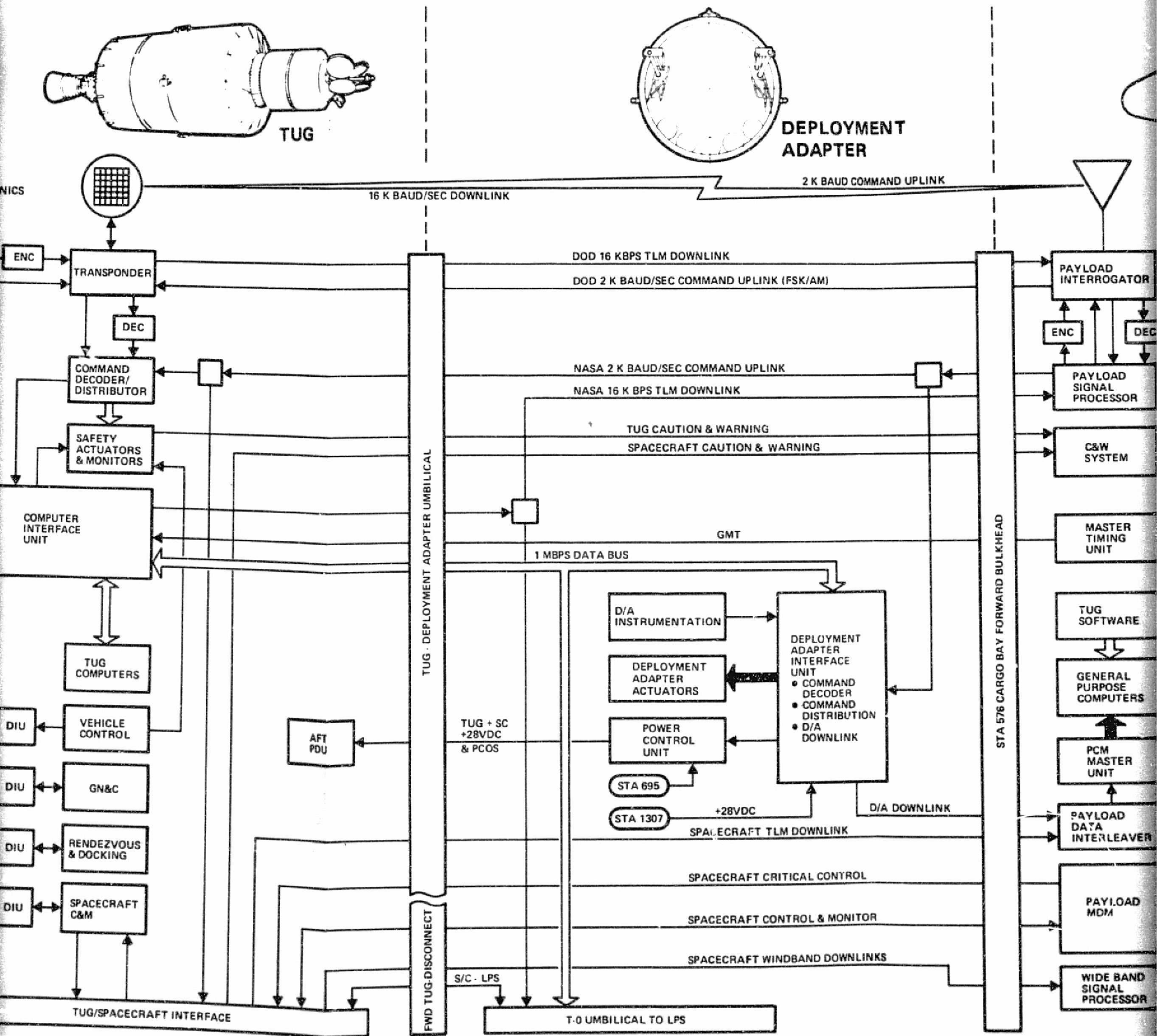


Figure 4.6-3. Tug/Orbiter Interface

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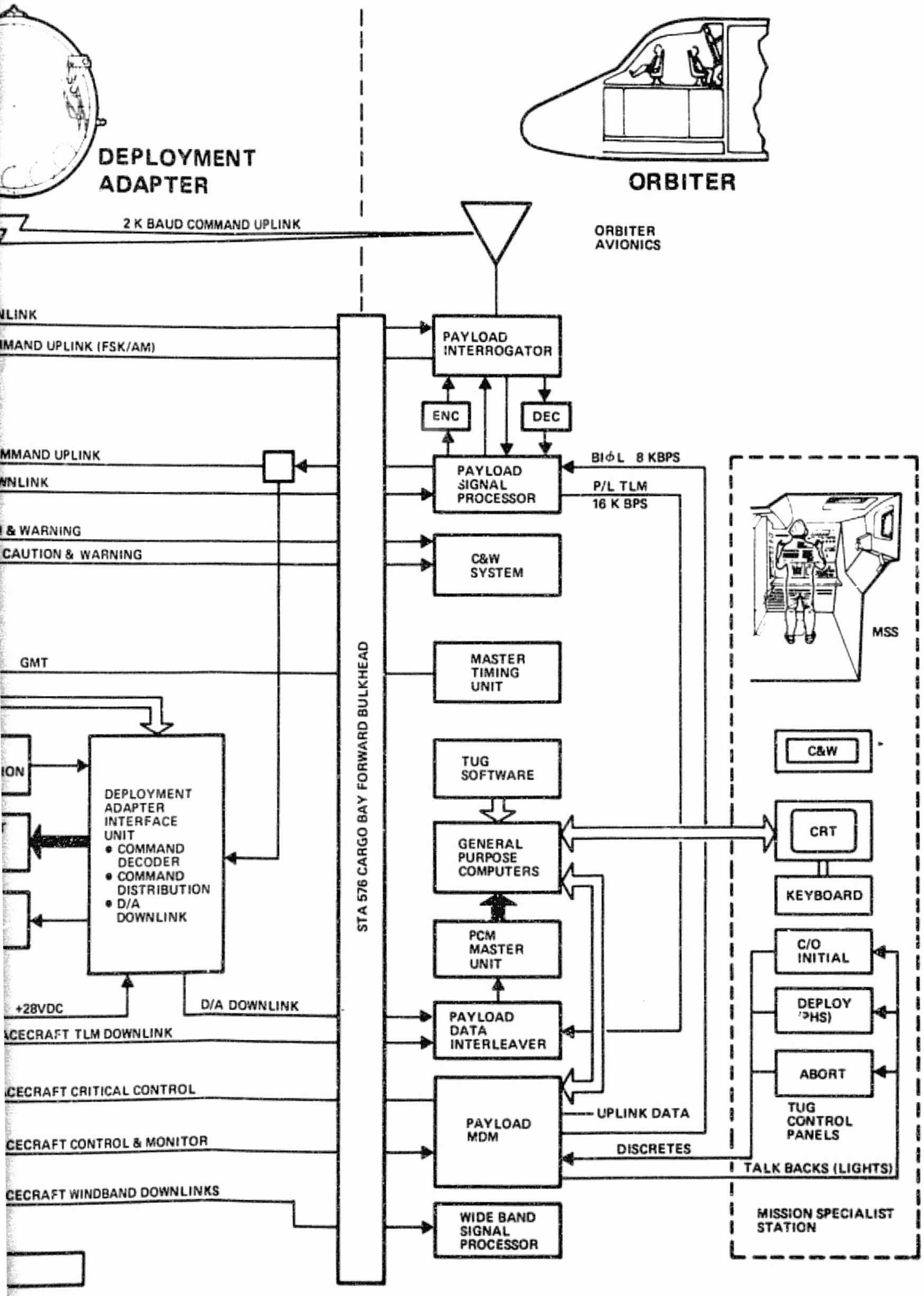

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The Orbiter payload support avionics available and used for the Tug/Orbiter interface includes the payload interrogator (PI), payload signal processor (PSP), C&W electronics, master timing unit (MTU), payload data interleaver (PDI), payload multiplexer-demultiplexer (MDM), and limited use of the Orbiter's general-purpose computer system, data recorders, and communication system.

The equipment and interface specifications affecting its use are described in document JSC-07700, Section 14 (Revision C, Change 7); selected portions of this document showing functional block diagrams and interface characteristics are included in Appendix D for reference.

In the diagram of Figure 4.6-3, Tug use of Orbiter avionics equipment located at and associated with the Mission Specialist Station (MSS) is also assumed. This capability includes Orbiter-supplied CRT and keyboard, associated alphanumeric display electronics, and Orbiter C&W display devices. Tug-provided unique equipment required in the aft crew area includes Tug two operations control panel located at the MSS and one control panel at the payload handling station (PHS) for control and monitoring of Tug validation, deployment, and activation functions.

Judicious use of the present Orbiter payload support capability was assumed in the recommended configuration to 1) reduce Tug design and development costs by not duplicating Orbiter payload support functions, 2) simplify Orbiter/Tug operations on the ground and in flight, 3) reduce the number, weight, and complexity of the physical interfaces at Tug/Orbiter bulkheads, and 4) take advantage of the high level of Orbiter redundancy and built-in test (BIT) capability to increase Tug/Orbiter operational reliability and safety. Less Tug unique equipment and interfaces installed into the Orbiter should aid turnaround time and assist interface test and checkout; during in-flight operations crew familiarity with standard Orbiter hardware should ease crew operation associated with Tug.

All Orbiter payload support equipment associated with the Tug/Orbiter interface is redundant except for the payload data interleaver and the PCM recorder unit. In addition, all Tug avionic functions employ dual redundancy to achieve operational reliability. In like manner, all major uplinks and downlinks associated with the Tug/deployment adapter/Orbiter interface are redundant (and use the corresponding redundancy level associated with the Tug and Orbiter interface avionics units.

A summary of the interface hardware required is presented in Tables 4.6-4 through 4.6-6. These interfaces are briefly described below. Interface characteristics referenced are compatible with the payload support equipment described in JSC-07700.

Tug Uplink Commands. During Tug attached to Orbiter operational phases the Tug uplink command interface will allow commands to be transmitted to the Tug,

Table 4.6-4. Tug Aft Cabin Equipment Requirements

Requirement	Capabilities	Supplier	Location	Power (AVE)	Wt, lb (kg)	Panel Space, in. (cm^2)
Data Control Processor	Real time, time shared, 16 bit word, 20 kops, dedicated use all mission phases, redundant.	Orbiter	GPC			
TLM Decom	PCM decoder, two channels (redundant) at 16 kbps, data accessible by payload software.	Orbiter	PSP, PDI, Master PCM Unit			
I/O	TIME Code: GMT accurate to 1 ms; 30 discrete. Inputs and outputs to aft crew cabin.	Orbiter	MTU MDM			
Software	Tug support executive software control of five S/W categories:	Tug/ Orbiter	GPC			
Application S/W	Real time monitor/C&W Initialization/status Deploy/capture RF communications Utility & control			See Note	See Note	See Note
Common Storage	TLM tables, interface tables					
Data Storage			GPC			
Operating Memory	15 k words	Orbiter				
Rapid Access (1 sec)	10.7 k words					
Communications						
Hardwired Uplink	2 k baud/sec, BI – Ø – L (redundant).	Orbiter	PSP			
Hardwired Downlink	16 k baud/sec, two redundant channels (DOD/NASA + D/A).		PSP			
RF	Data processor interface, transmitter/receiver, S-Band DOD/NASA, redundant components.		PI			
Uplink	2 k baud/sec.					
Downlink	16 k baud/sec.					
Crew Interface	CRT & keyboard (redundant).	Orbiter	MSS			
Panels	C&W electronics & annunciators.	Orbiter	MSS			
	Tug master caution/warning lights.	Tug	MSS	10	1(.45)	3 (20)
	Tug deployment/capture panel.	Tug	PHS	20	4(1.8)	23 (148)
	Tug initialization & safing panel.	Tug	MSS	20	6 (2.7)	48 (310)
	Tug abort control panel.	Tug	MSS	20	4 (1.8)	23 (148)
	Tug panel control electronics.	Tug	MSS	30	5 (23)	0

Note: Orbiter supplied standard payload support equipment, reference NASA Doc. No. JSC-07700, Vol. XVI or applicable NAR specification.

Table 4.6-5. Tug Cargo Bay Avionic Equipment

Requirement	Capabilities	Supplier	Location	Power (watts)
Deployment Adapter Interface Unit	Tug/Orbiter avionics; I/F.	Tug	D/A	75
Command Decoder & Distributor	Decode D/A commands from Orbiter 2k baud Bi-ϕ-L uplink (redundant).			
D/A PCM Downlink	Format & transmit D/A PCM data to Orbiter PDI (redundant).			
Instrumentation	Monitor D/A controls actuators and safety functions.	Tug	D/A	75
Power Control Unit	Control prime & backup power to Tug/SC, and Tug PCOS.	Tug	D/A	200 (pk)
Actuators	Control of D/A abort, deployment & capture functions.	Tug	D/A	See Note
He Valves				See Note
Rotary Deployment				355
Capture Latches				448
D/A Junction Box	Cable & signal routing terminal for Tug & S/C to Orbiter interface.	Tug	D/A	-
S/C Junction Box	Optional cable & signal routing terminal for S/C interface.	S/C	D/A	-
Forward Junction Box	Optional S/C wiring terminal for spacecraft functions.	S/C	Fwd. Discon.	-

Note: Power requirements are mission-phase dependent.
Reference Vol. II, Tables 4.6-11 and 4.6-12.

Table 4.6-6. Tug/Orbiter Interface Cable Kits

Item	Function	From	To
1	Tug/Spacecraft End Power	Orb. Sta. 695	D/A PCU
2	D/A Power	Orb. Sta. 1307	D/A IU
3	Tug/Spacecraft Prelaunch Functions (A1)	D/A J/B	Orb. Sta. 1307
4	Tug/Spacecraft Prelaunch Functions (A2)	Orb. Sta. 1307	Orb. Sta. 1439 (T-O Fuel Panel)
5	Tug/Spacecraft Prelaunch Functions (B1)	D/A J/B	Orb. Sta. 1307
6	Tug/Spacecraft Prelaunch Functions (B2)	Orb. Sta. 1307	Orb. Sta. 1439 (T-O Oxidizer Panel)
7	Tug/Deployment Adapter Digital Uplink/Downlink (A1)	D/A J/B	Orb. Sta. 1307
8	Tug/Deployment Adapter Digital Uplink/Downlink (A2)	Orb. Sta. 1307	Orb. Sta. 576
9	Tug/Deployment Adapter Digital Uplink/Downlink (A3)	Orb. Sta. 576	Orbiter PI, PSP, PDI, MTU Units
10	Tug/Deployment Safety Adapter Monitors (A1)	D/A J/B	Orb. Sta. 1307
11	Tug/Deployment Safety Adapter Monitors (A2)	Orb. Sta. 1307	Orb. Sta. 576
12	Tug/Deployment Safety Adapter Monitors (A3)	Orb. Sta. 576	Orbiter C&W Ele. Units
13	Tug Control Panel Harness	MSS, PHS	Orbiter MDM Units
14	Tug Control Panel Power Harness	MSS, PHS	Orbiter Aft Cabin +28 vdc

deployment adapter, or spacecraft through Orbiter payload interrogator/payload signal processor unit. For NASA missions these commands will be routed from the Orbiter PSP units to the command decoder unit associated with the Tug, spacecraft, or deployment adapter. Each command decoder unit will respond only when the uplink command data contains that unit's unique address. In this manner the single uplink channel associated with each PSP unit may be used to communicate with all payload functions within the cargo bay. Each uplink channel will communicate at a 2k baud per second information data rate through a Bi-ø-L signal format. Signal characteristics associated with the PSP at the PSP channel output are:

Logic level one	6 plus 0 minus 0.5 volts peak
Logic level zero	0 plus or minus 0.5 volts peak
Rise time*	Less than 1.0 microsecond
Fall time*	Less than 1.0 microsecond
Data code	Manchester II, bi-phase level (Bi-ø-L) as defined in MIL-STD-442
Impedance	75 plus ±7 ohms. single ended
Jitter	Not to exceed 0.5 percent of the pulse period

*The rise and fall time shall be measured between 10 and 90 percent of the voltage limits.

For DOD Tug missions, Orbiter uplink and downlink communication with the Tug and spacecraft are routed through the Orbiter's payload interrogator units. This interface will be implemented in basically the same manner as the NASA uplink, except that the data will be transmitted in a FSK/AM format (2k baud) and will be received at the Tug through the Tug's transponder unit(s). The Orbiter provides for installation of description and encryption units between the PSP and PI to allow communication of DOD secure mission data.

Signal characteristics associated with the PI uplink output are:

Signal type	FSK/AM Ternary
Data rate	2k baud
Waveform	FSK/AM
Tones	1 = 95 kHz ±0.01 percent 0 = 76 kHz ±0.01 percent S = 65 kHz ±0.01 percent

Sync AM = One kHz triangular ±0.01 percent
50 percent AM Modulation

Output impedance	75 ohms ±10 percent
Output termination	Single ended
Output power	10 dBm ± 3 dB

Tug Telemetry Downlink. During those operational phases in which the Tug is attached to the Orbiter, the Tug telemetry downlink interface will allow Tug telemetry data to be input to the Orbiter systems for processing on the Orbiter or for transmission to ground operations. For NASA missions, a dual downlink capability is achieved by routing each redundant channel of Tug TLM to the TLM input of each Orbiter PSP unit. The PSP unit will accept 16 kbps of telemetry data through its payload umbilical interface. The input signal characteristics are as follows:

Logic level one	3 to 6 volts peak
Logic level zero	0 plus or minus 0.5 volt peak
Rise time*	Less than 1.0 microsecond
Fall time*	Less than 1.0 microsecond
Data code	Manchester II, bi-phase level (Bi-ϕ-L) as defined in MIL-STD-442
Impedance	71 ±10 percent
Jitter	Not to exceed 0.5 percent of the bit period

*Rise and fall time measured between 10 and 90 percent of bit period.

DOD Tug TLM downlink data channels will be routed through the payload interrogator units to take advantage of signal conditioning capability and to allow Orbiter encryption and decryption of DOD transmissions. The PI input signal characteristics for DOD payload umbilical input channels is:

Data rate	16 kbps
Data waveform	PSK of 1.024 MHz carrier
Modulation	Bi-Ø-L or NRZ-L
Input impedance	75 ohms ±10 percent
Input termination	Single ended
Input power	6 dBm ±3 dB

It should be noted that in the recommended configuration, Tug spacecraft TLM downlink data will be routed to the Orbiter through the three (five total) available input channels associated with the payload data interleaver unit.

Time Code Data Transfer. To allow the Tug DMS to automatically update or verify its internal clock and time parameters (to 1 ms), GMT through an IRIG B code signal will be transmitted directly from the Orbiter master timing unit to the Tug digital interface unit. A redundant link will be employed to maintain high operational reliability.

Caution and Warning Monitor Signals. Three hardwired (not multiplexed) backup Tug warning signals (representing LO_2 and LH_2 tank pressure and N_2H_4 temperature) will be input to the Orbiter-supplied C&W electronics unit. These signals, in conjunction with C&W electronics unit logic and the C&W annunciator assembly will alert the Orbiter crew to out-of-tolerance safety-critical functions. The analog input signals associated with the C&W electronics unit's (CWE) Tug interface will be a positive, unipolar, grounded or ungrounded voltage in the range of zero to 5 volts dc from a source with an impedance of 100 ohms or less. Input circuit characteristics of the CWE are:

Type. Differential, balanced to CWE signal common.

Common Mode Rejection. For input voltage levels of minus 1.0 to plus 6.0 volts the common mode rejection shall be 40 dB minimum with ±5.0 volts peak common mode signal over a frequency range of dc to 1.0 kHz. For discrete input voltage levels of +18 to +37.5 volts, the presence of + or - 5.0 volts common mode signal over a frequency range of dc to 1.0 kHz shall not cause the input to be misinterpreted.

Input Current. For input voltage levels of -1.0 to +6.0 volts, input current shall not exceed 25 microamperes. For input voltages of +18 to +37.5 volts, input current shall not exceed 10.0 milliamperes.

Signal Return Isolation. Isolation between input signal returns shall be 100k ohms minimum with ±5.0 volts difference between return lines from dc to 1.0 kHz.

Alarm Limits. The CEW shall incorporate provisions to allow alarm limits for each system status input to be selected in 98 even increments over the range of 0.1 to 5.0 volts (nominal 50 millivolt steps).

Limit Detection. The CWE shall provide high-, low-, and dual-limit detection for each system status input as follows:

High Limit. An output signal shall be generated whenever the input voltage exceeds a predetermined limit. This limit may vary from +0.3 volt dc to +5.0 volts dc.

Low Limit. An output signal shall be generated whenever the input voltage falls below a predetermined limit. This limit may vary from +4.8 volts dc to +0.1 volt dc.

Dual Limit. An output signal shall be generated whenever the input voltage deviates above or below predetermined levels. The upper and lower limits may vary as described above, and the voltage range between the upper and lower limits may vary from +0.2 volt dc to +4.8 volts dc. Trigger point variation shall not exceed plus or minus 25 millivolts from the alarm limit.

Response Time. The CWE shall respond when one or more system status inputs is continuously out of limits for 100 ±25 milliseconds. The system status output shall remain activated until the input signal is continuously in limits for 100 ±25 milliseconds.

Safing Commands. Nine backup Tug safing commands allow control of Tug umbilical panels and abort functions should the primary Orbiter to Tug communication link become inoperative. These commands would use the same redundant multiplexed uplinks described above but would cause separate control output discretes to be generated when decoded by Tug or deployment adapter command decoder units. These discrete outputs would be transmitted directly to the safety or abort control actuators and would be capable of overriding any other existing actuator commands. This provides the Orbiter a fallback position in the event of all Tug and certain Orbiter computer failures.

D/A Downlink. Monitoring of deployment adapter operations and instrumentation will be accomplished through redundant multiplexed data links routed from two deployment adapter PCM telemetry units to two channels (of 5 available) of the Orbiter payload data interleaver unit. This data would then be made available for Orbiter or ground processing in the same manner as Tug TLM data. Input signal characteristics associated with this interface are listed in Table 4.6-7.

Orbiter/Tug Software Interfaces. During Orbiter ascent and through Tug deployment and capture operations the Tug will be supported by dedicated portions of the Orbiter general-purpose computer (GPC) system and associated Orbiter and Tug unique software. Thus software interfaces must be considered in addition to the traditional hardware interfaces associated with Tug/Orbiter operation. Failure by program management to acknowledge software requirements, the associated interfaces, and implementation concepts early in the system design cycle invariably results in cost and scheduled penalties later in the design, development, and operational phases of system life. These penalties usually result from a combination of the following types of problems:

a. Software becomes the critical path in the system development plan.

b. Software operational and bulk memory requirements will double.

c. Much hardware and software redesign activity will be required during final system integration and validation phases.

Table 4.6-7. PDI Data Input Characteristics

Input Interface. Each of the following payload signals is transmitted on a separate twisted shielded pair (TSP) cable:

a. Clock Signal. The clock signal shall be return-to-zero at 50 percent duty cycle. The duty cycle shall be accurate to within ±5 percent of the clock period not to exceed 10 microseconds, whichever is less. Rise and fall times shall not exceed 0.5 microseconds.

b. Data Signal. PCM telemetry formats shall conform to the NASA Aerospace Data Systems Standard (ADS), Document X-560-63-2 and telemetry working group, Inter-Range Instrumentation Group (IRIG), Document 106-73. The input data signal shall be accurate to within ±5 percent of the clock period, not to exceed 10 microseconds. Rise and fall times shall not exceed 0.5 microseconds. Data leading-edge skew when referenced to the clock signal shall not exceed ±5 percent of the clock period or a maximum of 10 microseconds, whichever is less.

c. Minor Frame Sync Signal. Minor frame synchronization signal shall have a minimum pulse width equal to the clock period times the duty cycle. The maximum minor frame sync pulse width allowed is equal to the length of the minor frame sync word. Rise and fall times shall not exceed 0.5 microseconds. Leading edge skew shall not exceed ±5 percent of the clock period or a maximum of 10 microseconds, whichever is less.

d. Major Frame Sync Signal. Major frame synchronization signal shall have a minimum pulse width equal to the clock period times the duty cycle. The maximum major frame sync pulse width allowed is equal to the length of the minor frame sync word. Rise and fall times shall not exceed 0.5 microseconds. Leading edge skew shall not exceed ±5 percent of the clock period or a maximum of 10 microseconds, whichever is less.

Input Logic States. The logical one ("1") state shall be 5 volts ±2 volts. The logical zero ("0") state shall be 0.0 volts ±1 volt.

Input Data Rates. Telemetry data rates shall not exceed 64.0 kbps from any one channel.

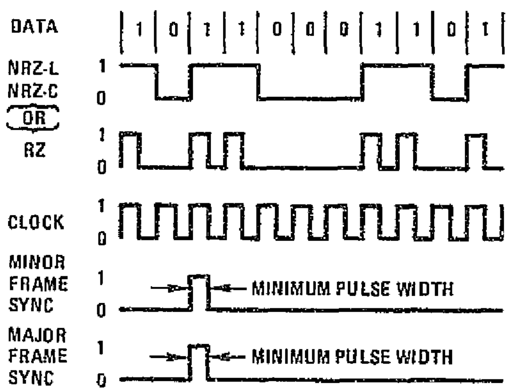
Signal Cables. Input PDI signal cables shall be two-conductor twisted shielded jacket cable having a distributed capacitance of less than 50 picofarads per foot and impedance of 70 ohms ±10 percent.

Table 4.6-7. PDI Data Input Characteristics (Contd)

Signal Cable Length. The cable length may be up to 120 feet between the payload line drivers and the PDI.

Signal Waveform Distortion. Overshoot and undershoot of the received signals shall be less than 20 percent of signal levels.

Timing. Input timing signals shall conform to the accompanying timing diagram.



Early predevelopment software/hardware integration will eliminate or alleviate these problems.

The paragraphs below and those that follow in Section 4.6.4 discuss the Tug/Orbiter software requirements at a preliminary concept level. It is hoped that Tug/Orbiter software requirement definitions may continue as the Orbiter software structure is developed and integration details become available.

The total set of software interfaces associated with Tug/spacecraft/Orbiter operation includes the following:

a. Intra-Tug Software. Communication of data between the various Tug DMS software modules.

b. Tug/Spacecraft Software. Software that transmits or receives data communicated between Tug and its spacecraft payload.

c. Tug/Orbiter Software. Software on the Tug and Orbiter that controls transmission or reception of multiplexed data across the physical Tug/Orbiter interface.

d. Tug/Ground Software. Software associated with communication of commands to the Tug and Tug telemetry to ground equipment during maintenance, preflight, Orbiter-attached and Tug-flight portions of the mission cycle.

e. Intra-Orbiter Tug/Orbiter Software. Orbiter-supplied and Tug unique software programs that function within the Orbiter's general-purpose computer (GPC) operating system in support of Tug/Orbiter operations.

The scope of the Tug/Orbiter software interface definition (for this study) was limited to preliminary definition of the requirements and implementation of the intra-Orbiter Tug software (item e above). This set of software consists of five categories of Tug-unique software programs (Table 4.6-8), which operate as application programs under the executive operating systems associated with the Orbiter general-purpose flight computer operating system (FCOS).

Table 4.6-8. Tug-Unique Orbiter Support Software

ID	Tug Support Software	Memory	Speed (Avg)
100	Tug real-time monitor	850	1.0 kOPS
200	Tug initialization, status	4,890	0.03
300	Tug deploy/capture	200	0.01
400	Tug RF control	2,225	0.1
500	Tug utility & control	505	0.5
Data Base	Common storage, tables, etc.	1,500	
TOTALS		10,170	2.0 kOPS

The data in the table indicates that the total mass storage required from the Orbiter is approximately 11k words. During normal operations, however, only two programs will operate simultaneously: 1) Tug critical function monitor, and 2) the program associated with the current operational event (i.e., rotate D/A up). Thus, actual working computer memory requirements should not exceed 5k words (program and data base) at any one time. These software estimates assume that the Orbiter GPC has provided a software operating system, and crew operator interface compatible with Tug unique software requirements.

The software structure assumed is a real-time operating system where the payload input/output is controlled through data base tables processed by the Orbiter executive. This simplifies the Tug application software tasks since all the telemetry processing, display input/output, mass memory interface, and system communications are handled with structured data blocks. This type of system is illustrated in Figure 4.6-4, which shows the Tug/Oribter hardware/software interface in block diagram form.

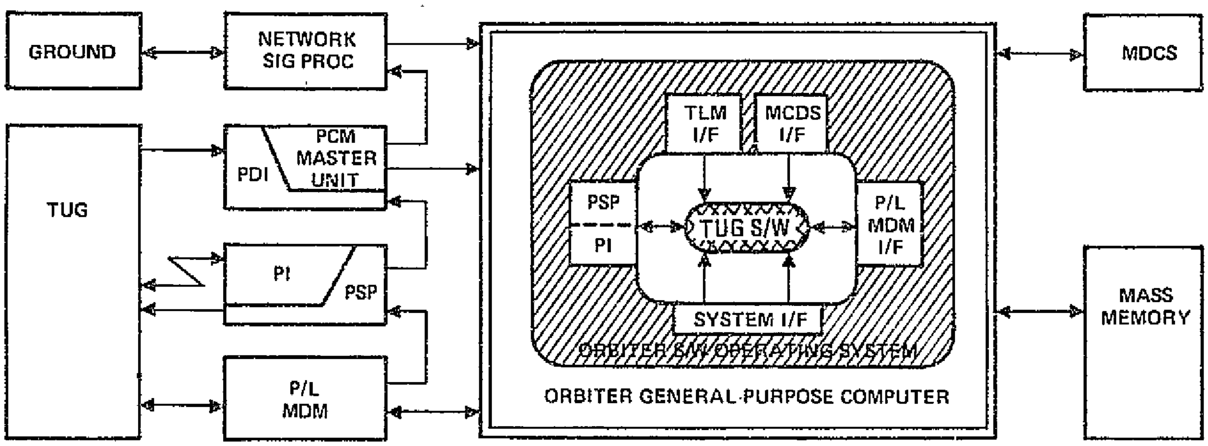


Figure 4.6-4. Tug/Orbiter Interface Software

A summary of the Tug-unique software requirements and ground rules associated with the Orbiter GPC system is presented in Table 4.6-9. It should be noted that the five Tug-unique software program categories may be divided into two groups consisting of 1) safety-critical programs and 2) nonsafety-critical programs. These two groups may reside in separate regions of the GPC system; however, it is required that the safety-critical programs (category 100, real-time monitor) be continually in residence in the redundant GPCs.

Table 4.6-9. Ground Rules for Use of Orbiter GPC Software

10 k words (32-bit) memory allocation (half word instructions — OK)

18 k adds/sec (time continually available)

Orbiter provided library (math) routines

Orbiter provided display formatting software (payload software will "input" to this)

Mass memory available for "program roll in", accessible within 1/2 to 8 seconds on command from payload software)

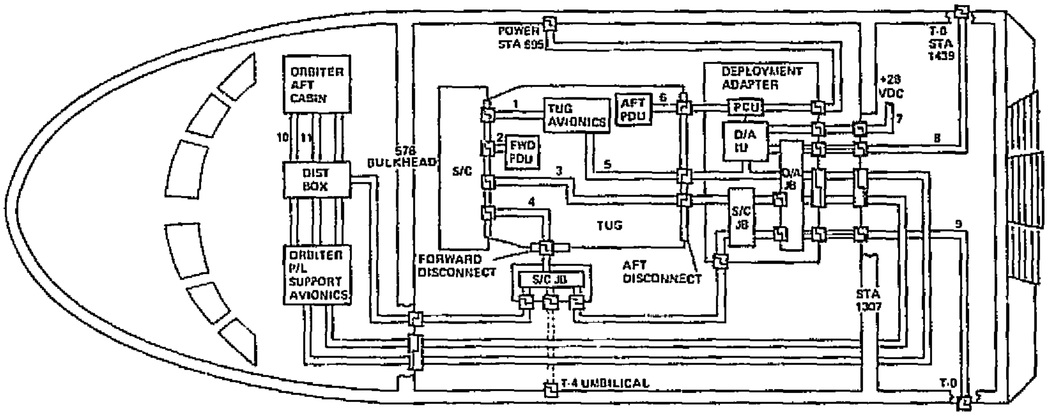
Table 4.6-9. Ground Rules for Use of Orbiter GPC Software (Contd)

Keyboard, CRT available to payload
External PCM decommutation of:
16 kbps Tug bit stream (through payload signal processor)
16 kbps deployment adapter bit stream (through payload data interleaver)
Spacecraft status monitoring and command programs provided by spacecraft user
GPC has backup input to C&W annunciator
Safety-critical data monitor software is resident in the GPC system continually, and cannot be superseded.
Nonsafety-critical data functions are grouped separately

4.6.2 ELECTRICAL UMBILICAL ROUTING SERVICE PANELS. The electrical service routing implementation for the spacecraft, Tug, deployment adapter, and Orbiter are shown in Figure 4.6-5. The various Tug and spacecraft interface functions are grouped according to function and identified by code numbers. Tug and payload C&W, safing control and on-orbit power functions (Codes 5, 3, 8, and 9) are routed through the Tug deployment adapter through the Orbiter aft cargo bay bulkhead at station 1307, thus providing hardwired control during all attached operations including predeployment and post-capture. A forward Tug disconnect (Code 4) is provided near station 961 for on-orbit and prelaunch checkout of Tug-spacecraft. This umbilical interface provides payload access to the Orbiter, T-0 umbilical panels and the T-4 umbilical panels with minimum weight penalty to the Tug vehicle.

Spacecraft junction box (JB) mounting facilities are provided at both the forward disconnect and on the deployment adapter to allow maximum spacecraft flexibility without adding additional weight to Tug or Orbiter systems. In like manner all Tug, deployment adapter, and spacecraft control and monitor signals are routed through the deployment adapter junction box for distribution to and from standard Orbiter interface connections at Orbiter station 1307. Redundant Tug (and spacecraft) uplinks and downlinks to ground are shown to be split, with each redundant set of signals routed through the separate T-0 umbilical panels, located on each side of the Orbiter at station 1439.

Power is supplied to the Tug/spacecraft and the deployment adapter through separate interfaces (Codes 6 and 7, respectively). Orbiter dedicated and backup power from station 695 is available to the Tug through the deployment adapter power control unit



ORBITER SERVICE REQUIREMENTS

	INTERFACE	STA. 576	STA. 1307 (TO AFT CABIN)	(T-0 UMBILICAL)
ORBITER CAPABILITY	TSP	207	169	202
	TP	98	98	-
	COAX	29	10	14
	CABLE B	6	2	-
TUG REQUIREMENTS	TSP	16	31	6
	TP	–	–	–
	COAX	–	–	2
	CABLE B	–	-	
SPACECRAFT REQUIREMENTS	TSP	121	121	15
	TP	–	–	24
	COAX	3	3	–
	CABLE B	–	–	–
COMBINED TUG AND SPACECRAFT REQUIREMENTS	TSP	137	152	21
	TP	–	–	24
	COAX	3	3	2
	CABLE B	–	–	–

UMBILICAL DETAILS

CODE	FUNCTION	FROM	TO
1	S/C UL, CONTROL/MONITOR	S/C	TUG
2	S/C POWER	TUG	S/C
3	S/C DL, C&W, SAFETY	S/C	ORBITER
4	S/C C/O, PRELAUNCH	S/C	ORB/LPS
5	TUG-D/A, UL, DL, C&W, TIME	TUG-D/A	ORBITER
6	TUG-S/C POWER	ORBITER	TUG
7	D/A POWER	ORBITER	D/A
8	TUG-S/C, UL, DL, DATA	TUG-S/C	LPS
9	TUG-S/C, UL, DL, DATA	TUG-S/C	LPS
10	TUG AFT CABIN WIRING	MSS	DIST/MDM
11	S/C AFT CABIN WIRING	PSS	DIST/MDM

Figure 4.6-5. Tug Electrical Services Routing

(PCU) for on orbit-checkout and validation operations, while deployment adapter power (dedicated and backup) is provided through Orbiter station 1307.

Tug and spacecraft control and monitor functions interface with Orbiter payload support avionics via connections at station 576. An Orbiter distribution box provides limited payload capability in routing signals to the aft crew station locations and selected payload support avionics. This configuration does not, however, allow payload unique equipment located in the aft crew station to interface with Orbiter payload support avionics (such as the MDM), thus it is recommended that all payload signals from both the aft crew cabin and cargo bay locations be routed through the Orbiter's payload signal distribution box.

In summary, the Tug/spacecraft/deployment adapter electrical service requirements fall within the current Orbiter capability except for the spacecraft requirement for 24 TP cables in the T-0 umbilical. It is recommended that these signals use the spare TSP cable available to satisfy this requirement.

4.6.3 TUG/PAYLOAD POWER REQUIREMENTS. An analysis was performed to determine the power requirements as a function of operational phase for the Tug, its spacecraft, the deployment adapter, and Tug-unique support equipment located in the

Orbiter aft cabin. These payload requirements were then compared with the Orbiter capabilities to determine if incompatibilities occur.

The resulting data indicates that sufficient power is available from the Orbiter to supply both Tug and spacecraft requirements during all Tug/Orbiter mission phases except Orbiter ascent, descent, and post-launch operations. During these mission phases, the Orbiter power allocated for payload functions is constrained to 350 watts average (420 watts peak) to the aft flight deck and 1000 watts average (1500 watts peak) to the Orbiter cargo bay interfaces. During normal ascent operations the combined Tug, spacecraft, and deployment adapter requirements are 1478 watts, thus exceeding Orbiter capability by 478 watts. This problem becomes even more significant if a Tug abort operation is required during ascent because 2413 watts of cargo bay power will be required.

During all other Tug/Orbiter operating phases, sufficient Orbiter power availability from cargo bay interfaces far exceeds that required by all Tug, deployment adapter, and spacecraft functions combined. The maximum cargo bay power requirements (2702 watts) occur during ground prelaunch operations when either: 1) 3000 watts average (4000 watts peak) are available, or 2) on-orbit power levels are available when the Orbiter is configured to require minimum power. The maximum on-orbit power required for Tug/deployment adapter/spacecraft functions occurs during Tug/spacecraft deployment operations when a total of 2603 watts are required. NASA Document JSC 07700 (change 6) indicates that while on on-orbit status, the Orbiter will provide 750 watts average (1000 watts peak) to the aft flight deck for payload-unique operation functions equipment, and either:

a. 7000 watts maximum (12,000 watts peak) at the mid-cargo bay electrical interface (station 695) using a payload-dedicated fuel cell.

b. 5000 watts maximum (8000 watts peak) at the second mid-cargo bay electrical interface when sharing a power source with the Orbiter or,

c. 3000 watts average (4000 watts peak) to the aft cargo bay electrical interface (station 1307).

It should be recognized that the 3000 watts available at the aft cargo bay is supplied through two 1500 watt interfaces, which may not be connected together by payload avionic circuitry.

The data discussed above representing the Tug/spacecraft/deployment adapter power requirement and the corresponding Orbiter capabilities as a function of mission phase is summarized in Table 4.6-10. In addition to the Orbiter cargo bay requirements, it is estimated that the Tug-unique control panel located within the Orbiter aft crew compartment will require an additional 100 watts during all Tug/Orbiter mission phases.

Table 4.6-10. Tug/Spacecraft and Deployment Adapter Power Requirements (Watts)

	Prelaunch	Ascent	Pre-Deployment	Deployment	Capture	Descent	Abort
Spacecraft	600	600	650	700	0	0	600
Tug Avionics	979	320	992	801	778	294	335
Tug Actuator	761	225	296	321	371	404	768
D/A Avionics	150	150	150	150	150	150	150
D/A Actuators	212	183	183	631	631	234	530
Tug plus S/C Totals	2340	1145	1938	1822	1149	698	1703
Deployment Adapter Totals	261	333	333	781	781	384	680
Cargo Bay Totals	2702	1478	2271	2603	1930	1082	2413

The spacecraft and Tug avionics power data analyzed above is based on inputs from companion on-going Space Tug studies (Space Tug avionics definition study and IUS/Tug Payload Requirements Compatibility Study). To establish the Tug and deployment adapter power requirements for electromechanical actuators (e.g., valves, motors, solenoids), all valves and actuators were identified, and their power, arm-safing, control, and monitor requirements were tabulated as a function of mission phase. Power requirements were then determined for each mission phase by summarizing the power requirement for the individual devices activated for the major event in each mission phase that required the most total power. The results of this tabulation are shown in Tables 4.6-11 and 4.6-12. It should be noted that this analysis was based on data from the Tug interface fluid schematic (I/T-74-010) dated 10-25-74. This schematic has been updated once since that time; however, it is not expected that the results obtained will differ to any significant degree. This schematic is presented for reference in Figure 4.6-6.

Several alternative methods of providing power to the cargo bay were investigated to alleviate the insufficient ascent power problem. Methods considered included 1) use of deployment adapter batteries, 2) use of Tug batteries, and 3) use of Tug fuel cells. Option 3 was selected.

The power distribution concept recommended is shown in Figure 4.6-7. In this concept the deployment adapter would receive power from the Orbiter aft cargo bay interfaces during all mission phases, while the Tug and spacecraft would nominally receive power from the Orbiter mid-cargo bay interface only during prelaunch operations. At all other times the Tug/spacecraft power would be supplied through the Tug fuel cells, which would be activated just before launch. Although use of Orbiter power for Tug/spacecraft functions would not normally be required during Tug/Orbiter on-orbit operations, the backup capability would be available in the event of Tug multiple fuel cell failure or if spacecraft checkout power requirements exceeded Tug fuel cell capability.

The Orbiter station 695 power service panel was selected as the Orbiter cargo bay Tug/spacecraft power source because of the 7 kW Ave (12 kW peak) power availability at this point. The deployment adapter avionics are connected to the Orbiter station 1307 power interface because of its close proximity and due to the fact that deployment adapter power requirements are within the capability of this interface (1.0 kW ascent, 1.5 kW on orbit).

The Tug/spacecraft/Orbiter power distribution diagram indicates that both the primary and backup Orbiter power sources from the Orbiter station 695 power service panel will be input to the Tug deployment adapter power control unit. Power control logic and switches in this unit will automatically switch from Orbiter prime power to the back-up mode in the event of an Orbiter prime power interruptive without violating the Orbiter ground rule by connecting multiple Orbiter fuel cell outputs together. In addition a separate power control switch is provided to control Orbiter power application

Table 4.6-11. Tug Helium Valves Under Orbiter/GSE Control

Valve No.	Name/Function	Normally Open	Normally Closed	APS Arm/Safe	Main Engine Arm/Safe	Control Power (W)	Prelaunch	Orbiter Ascent	Tug Initialization	Tug Deployment	Orbiter Descent	Abort Dump	Abort Safe	
T-H-001	He High Pressure Fill Valve 1		X			84	84				84	84	84	
-002	He High Pressure Fill Valve 2		X			84						84	84	
-003	He Vent Valve 1		X			28								
-004	He Vent Valve 2		X			28								
-005	He Vent Valve 3	X			X	28								
-006	He APS Pressurization Valve 1	X		X		84								
-007	He APS Pressurization Valve 2	X		X		84								
-008	He APS Pressurization Vent Valve 1		X			84								
-009	He APS Pressurization Vent Valve 2		X			84								
-010	He APS Pressurization Vent Valve 3	X		X		84								
-011	He LH_2 Fuel Tank Pressurization 1		X			84	84				84	84	84	
-012	He LH_2 Fuel Tank Pressurization 2		X			84						84	84	
-013 A&B	He GH_2 Vent Valve Control 1		X			28	56							
-014	He GH_2 Vent Valve Control 2		X			28								
-015 A&B	He LH_2 Fill, Drain & Dump Control 1		X			28	56					56	56	
-016 A&B	He LH_2 Fill, Drain & Dump Control 2		X			28						56	56	
-017	He RL10 Engine Prevalve		X		X	28								
-018	Spare													
-019 A&B	He LO_2 Fill, Drain & Dump Valve Control 1		X			128	256					256	256	
-020	He LO_2 Fill, Drain & Dump Valve Control 2		X			128						256	256	
-021	He RL10 Engine Feed Pre-Valve		X		X	28								
-022	He LO_2 Tank Pressurization Valve 1		X			28	28					28	28	
-023	He LO_2 Tank Pressurization Valve 2		X			28						28	28	
-024 A&B	He GO_2 Vent Valve Control 1	X				28	56							
-025	He GO_2 Vent Valve Control 2	X				28								
-026	He RL10 LH_2 Pre-Valve Control		X		X	28								
-027	He RL10 LH_2 Engine Main. Valve Control		X		X	28								
-028	He RL10 LO_2 Engine Main. Valve Control		X		X	28								
-029	He LO_2 Topping Valve Control		X			28								
-030 thru -039	Spares													

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Table 4.6-11. Tug Helium Valves Under Orbiter/GSE Control (Contd)

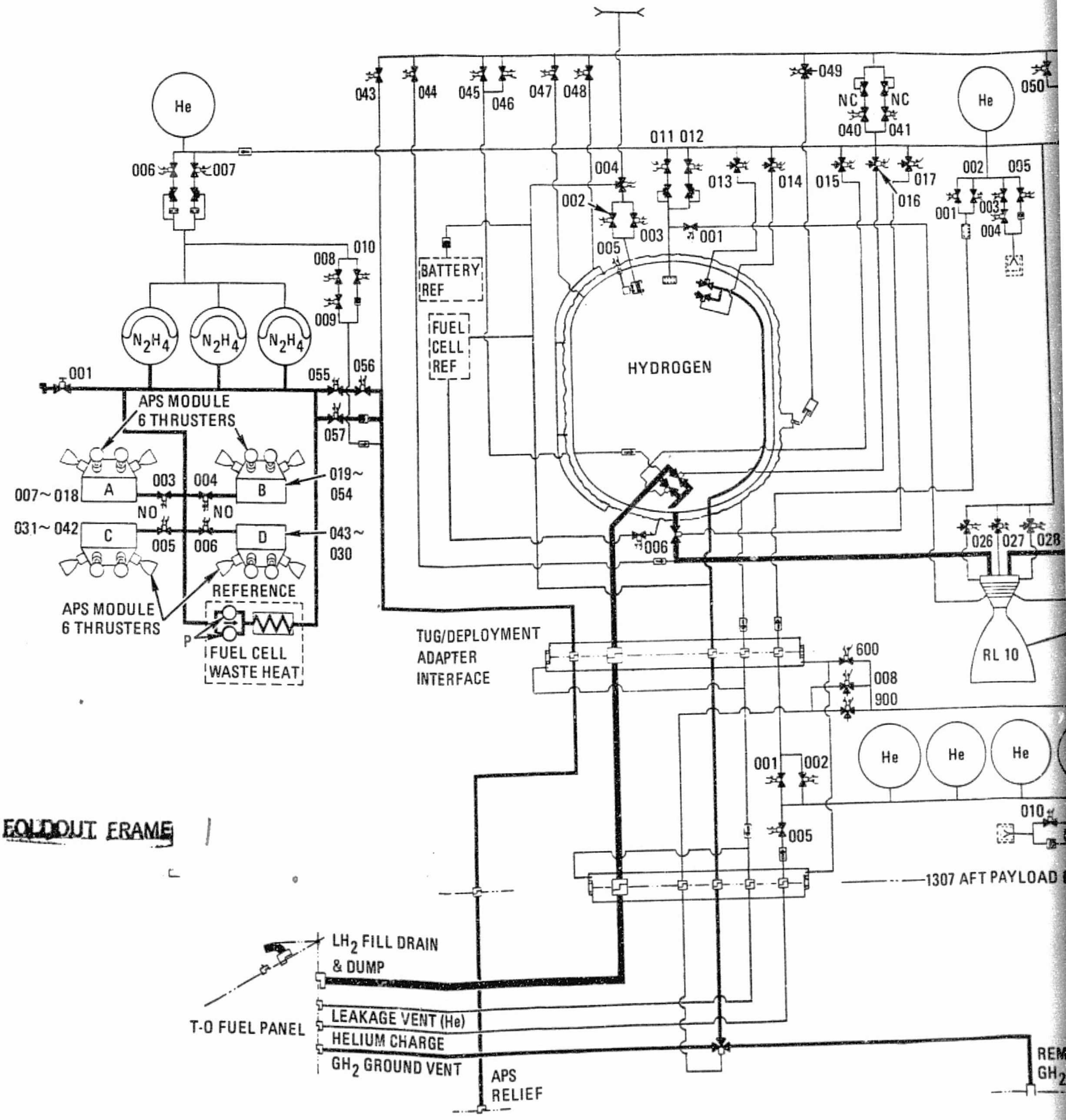
Valve No.	Name/Function	Normally Open	Normally Closed	APS Arm/Safe	Main Engine Arm/Safe	Control Power (W)	Prelaunch	Orbiter Ascent	Tug Initialization	Tug Deployment	Orbiter Descent	Abort Dump	Abort Safe	
T-H-040	He Purge Manifold Supply Valve 1		X			28			28		28			
-041	He Purge Manifold Supply Valve 2		X			28								
-042	Spare		X			28								
-043	He APS Relief Line Purge		X			28								
-044	He LH_2 Engine Feed Line Purge		X			28								
-045	He LH_2 Propellant Tank Fill & Dump Line 1 Purge		X			28							28	
-046	He LH_2 Propellant Tank Fill & Dump Line 2 Purge		X			28	28				28		28	
-047	He LH_2 Leakage Containment Memb. Purge		X			28	28				28		28	
-048	He LH_2 Tank Insulation Purge	X				28		28	28	28	28		28	
-049	He LH_2 Purge Bag Vent Control		X			28	28	28	28	28			28	
-050	He RL10 Engine Feed Line Purge		X			28								
-051	He LO_2 Engine Feed Line Purge		X			28								
-052	He LO_2 Fill, Drain & Dump Line Purge 1		X			28							28	
-053	He LO_2 Fill, Drain & Dump Line Purge 2		X			28							28	
-054	He LO_2 Tank Insulation Purge		X			28	28				28		28	
-055	He LO_2 Leakage Containment Memb. Purge		X			28	28				28		28	
-056	He LO_2 Purge Bag Vent Control	X				28		28	28	28	28		28	
LO_2 (Oxidizer; = O														
T-O-001	GO_2 Autogenous Pressurization Valve		X		X	28								
-002	GO_2 Zero-G Vent Valve 1		X			28		28	28	28				
-003	GO_2 Zero-G Vent Valve 2		X			28								
-004	GO_2 Zero-G Vent Selector Valve		X			28				28				
-005	LO_2 Zero-G Vent Mixer Motor		X			75		75	75	75				
-006	LO_2 Fuel Cell Feed	X				28								

Table 4.6-11. Tug Helium Valves Under Orbiter/GSE Control (Contd)

Valve No.	Name/Function	Normally Open	Normally Closed	APS Arm/Safe	Main Engine Arm/Safe	Control Power (W)	Prelaunch	Orbiter Ascent	Tug Initialization	Tug Deployment	Orbiter Descent	Abort Dump	Abort Safe
LH_2 (Fuel) = F													
T-F-001	GH_2 Autogenous Pressurization Valve		X		X	28							
-002	GH_2 Zero-G Vent Valve 1		X			28		28	28	28			
-003	GH_2 Zero-G Vent Valve 2		X			28							
-004	GH_2 Zero-G Vent Selector Valve		X			28				28			
-005	LH_2 Zero-G Vent Mixer Motor		X			10		10	10	10			
-006	LH_2 Fuel Cell Feed	X				78							
	Fuel Cell H_2O_2 Water Relief Valve					28							
N_2H_4 (APS) = A													
T-A-001	N_2H_4 Fill & Drain Valve (Manual)		X			28							
-002	Spare		X			28							
-003	N_2H_4 Thruster Module A Shut-Off Valve		X	X		28							
-004	N_2H_4 Thruster Module B Shut-Off Valve		X	X		28							
-005	N_2H_4 Thruster Module C Shut-Off Valve		X	X		28							
-006	N_2H_4 Thruster Module D Shut-Off Valve		X	X		28							
-007	N_2H_4 APS Thruster Control Valve		X	X		28							
-018	N_2H_4 APS Thruster Control Valve		X	X		28							
-019	N_2H_4 APS Thruster Control Valve		X	X		28							
-030	N_2H_4 APS Thruster Control Valve		X	X		28							
-031	N_2H_4 APS Thruster Control Valve		X	X		28							
-042	N_2H_4 APS Thruster Control Valve		X	X		28							
-043	N_2H_4 APS Thruster Control Valve		X	X		28							
-054	N_2H_4 APS Thruster Control Valve		X	X		28							
-055	N_2H_4 Relief Valve 1		X			28							
-056	N_2H_4 Relief Valve 2		X			28							
-057	N_2H_4 Relief Valve 3	X		X		28							

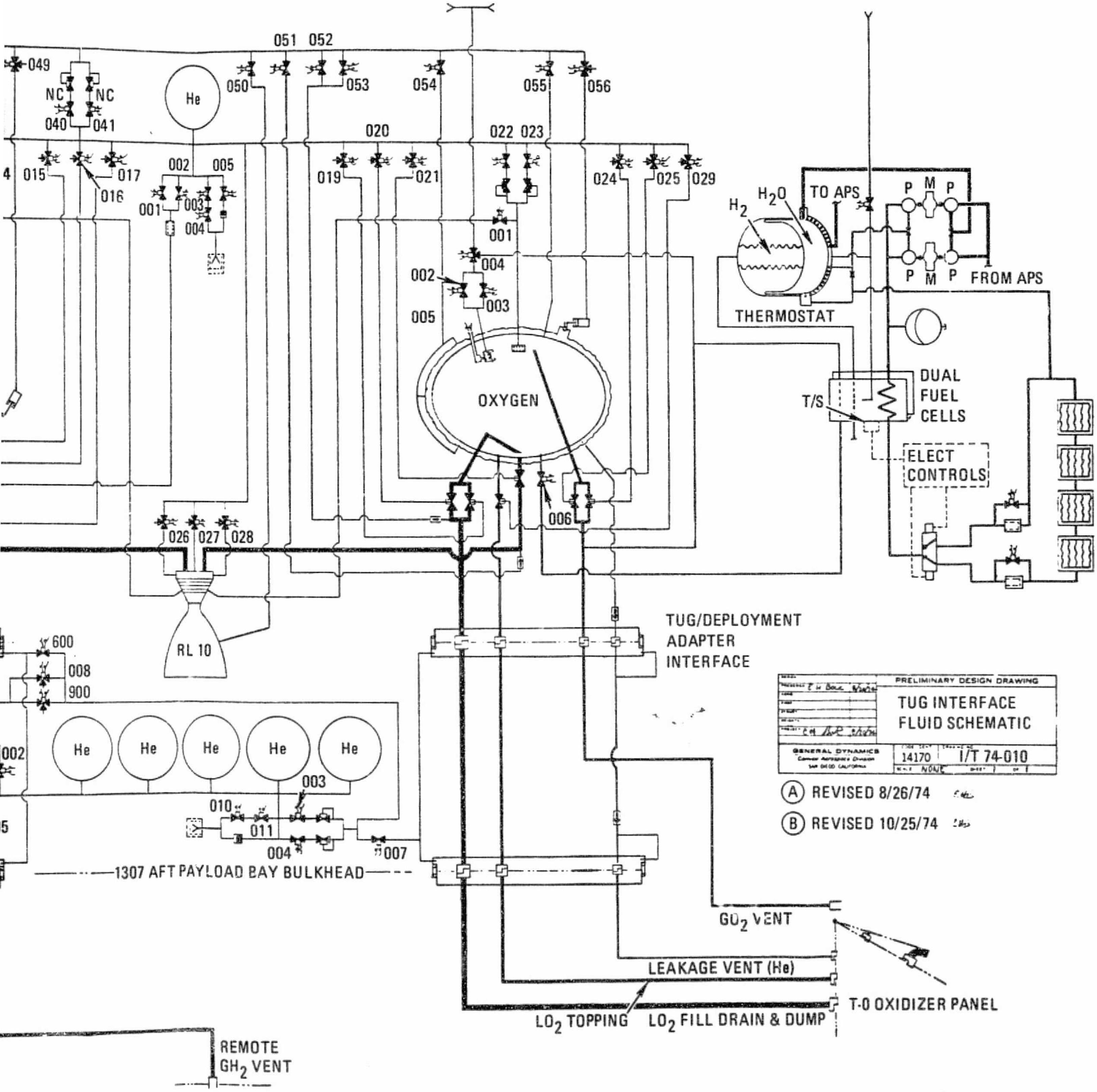
Table 4.6-12. Deployment Adapter Actuators and Valves

Identification Number	Name/Function	Normally Open	Normally Closed	D/A Arm/Safe	Control (Amp) Power	Monitor Data	Nominal Value	Accuracy	Prelaunch	Orbiter Ascent	Tug Initialization	Tug Deployment	Orbiter Descent	Abort Dump	Abort Safe
D/A Valves															
D/A-H-001	He Supply System Primary Valve 1		X		84	4000-TO-50 psi	3200 psi	±50 psi	84				84	84	84
-002	He Supply System Pr[illegible]ry Valve 2		X		84	4000-TO-50 psi	3200 psi	±50 psi						84	84
-003	He Supply System Secondary Valve 1		X		84	60-TO-0 psi	50 psi	±1 psi	84		84	84	84		84
-004	He Supply System Secondary Valve 2		X		84	60-TO-0 psi	50 psi	±1 psi							84
-005	He Bottle Fill (Deployment Adapter) Valve		X		128	ON/OFF	3200 psi	±50 psi	128						128
-006	He Ground Hold Fuel Panel Purge Valve		X		33	ON/OFF	50 psi	±1 psi		33	33	33			33
-007	He Ground Hold Oxidizer Purge Valve		X		33	ON/OFF	50 psi	±1 psi		33	33	33	33		33
-008	He Flight GH_2 Vent Valve 1		X	X	33	ON/OFF	50 Psi	±1 psi		33	33	33			
-009	He Flight GH_2 Vent Valve 2		X	X	33	ON/OFF	50 psi	±1 psi							
-010	He Deployment Adapter Vent 1		X		33	ON/OFF	50 psi	±1 psi							
-011	He Deployment Adapter Vent 2		X		33	ON/OFF	50 psi	±1 psi							
D/A Actuators															
D/A-DCU-001	Deployment Control Arm/Safe Switch	X			224	Arm or Safe									
-002	Fluid Umbilical Panel Control 1	X		X	150	Engaged or Disengaged									
-003	Fluid Umbilical Panel Control 2	X		X	150	Engaged or Disengaged									
-004	Tug Rotation Actuator	X		X	355	Up or Down									
-005	Electrical Umbilical Panel Control	X		X	150	Engaged or Disengaged									
-006	Tug Capture Latches (16)	X		X	448	Engaged or Released					448				



FOLDOUT FRAME

Figure 4.6-6. Preliminary Tug Interface Fluid Schematic



FOLDOUT FRAME 2

to the Tug and Spacecraft. Where it is desired to connect Orbiter power to the Tug/spacecraft (descent operations); deployment adapter commands initiated via the Tug payload support equipment are transmitted to the Tug vehicle power change-over switch, causing it to assume the external power mode (disconnecting the Tug from its fuel cells), then power is applied to the Tug via the deployment adapter power control switch. The Tug is configured so that when external power is applied to the Tug its critical power bus, which supplies the Tug CIU/DIU communication system, is energized thus allowing selective power control of the other Tug systems or application of power to the Tug payloads. This configuration, therefore, allows power to be applied to payloads during prelaunch and maintenance operations without activation of the total Tug avionics system. Additionally, a ground transfer power interface is provided for power application to the Tug/spacecraft during prelaunch ground handling operations. This allows Tug or spacecraft safety functions to be continuously monitored (if required).

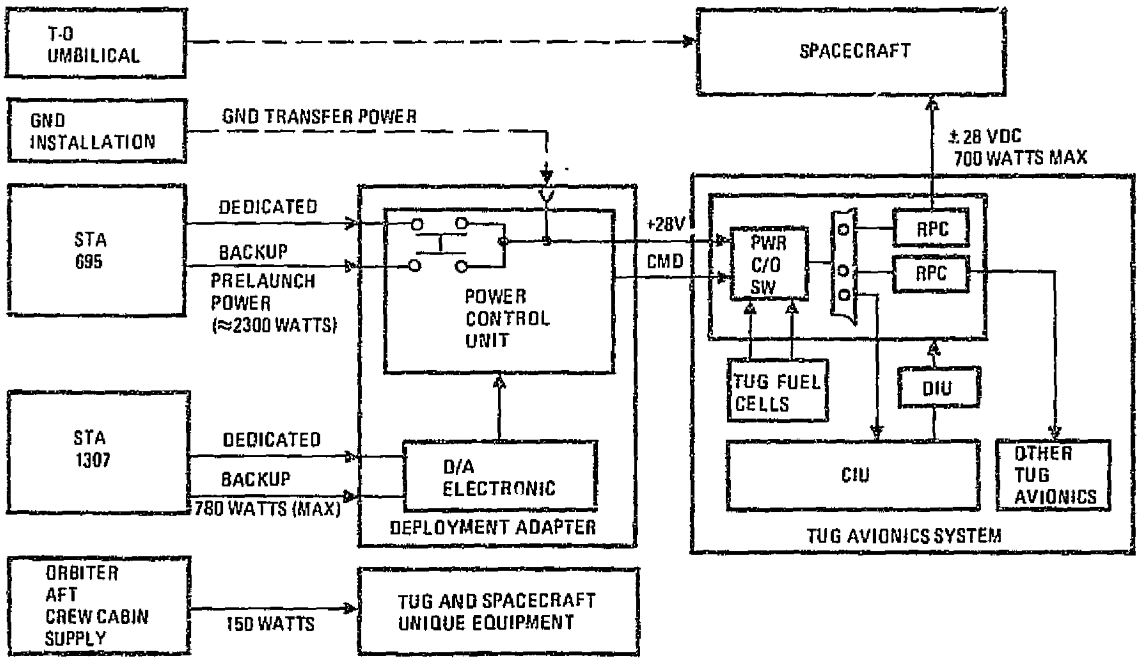


Figure 4.6-7. Tug Power Distribution Diagram

4.6.4 OPERATIONAL DESCRIPTION. The Tug/Orbiter interface operational characteristics are described in this section for prelaunch, launch/descent, and on-orbit operations. The subjects addressed include: operational command and monitor functions, abort, C&W operations, and the associated crew control and Orbiter/Tug support equipment and software.

To augment the information presented in this section, a summary of the Orbiter payload support equipment and its associated capability is included in Appendix D of this volume, and the Tug avionic system and Orbiter/spacecraft interfaces are summarized in Volume III, Section 4.

OPERATION	GROUND	ORBITER	TUG
MONITORS			
C&W	B/U	X	
TUG STATUS	B/U	X	
CONTROLS			
SAFETY CRITICAL	B/U	X	
VENTS	B/U	B/U	X
PURGES	B/U	B/U	X
UPDATE G&N	B/U	X	
UMBILICAL MECHANISMS		X	
FORWARD LATCHES		X	
D/A ROTATION		X	
D/A LATCHES		X	
FUEL CELL START	X	B/U	
FUEL CELL STOP	B/U	X	
POWER CHANGEOVER		X	
PREDEPLOYMENT CHECKOUT	X		
PREDEPLOYMENT STATUS	B/U	X	
ACS ARMING	B/U	X	
ENGINE NOZZLE	X	B/U	
LOITER	X	B/U	
MAIN PROPULSION ARMING	X	B/U	
MISSION SEQUENCE START	X	B/U	
MAIN PROPULSION SAFING	X	B/U	
PROPELLANT DUMP	X		
PRECAPTURE CHECKOUT	X		
ACS SAFING	B/U	X	
FUEL CELL DEACTIVATION	B/U	X	
ABORT		X	

- ORBITER IS PRIME FOR SAFETY MONITOR & CONTROL
- ORBITER IS PRIME FOR NORMAL PREDEPLOYMENT/DEPLOYMENT/CAPTURE OPERATIONS
- ORBITER PRIME FOR ABORT CONTROL
- GND PRIME FOR TUG CHECKOUT & ANOMALY ISOLATION (ORBITER HAS LIMITED CAPABILITY VIA CRT & UTILITY OPTIONS)
- ORBITER B/U FOR GND RF COMMANDS

Figure 4.6-8. Recommended Interface Operations Allocation

4.6.4.1 Tug/Orbiter Operations per Mission Phase. The recommended baseline operational allocation of control and monitoring responsibilities for ground, Orbiter and Tug are shown in Figure 4.6-8. This configuration includes recommendations from the various sensitivity analyses and from coordination meetings among NASA/MSFC and the five Tug study contractors. For this recommended operations plan, the ground facilities are responsible for operations involving detailed data analysis, large data processing hardware/software activities, and for operations where detailed knowledge of the Tug or its subsystems is needed. The launch complex ground facilities (LPS) will be responsible for Tug/spacecraft prelaunch checkout, interface verification, Tug propellant loading operations, and monitor and control for caution and warning functions. These operations will normally be performed by launch crew personnel using launch GSE (LPS), which interfaces to the Tug/deployment adapter through the Orbiter T-0 umbilical panels. It should be noted that, although ground operations will employ Tug independent uplink/downlink capability through the T-0 umbilical, it is possible and recommended that the normal Orbiter/ground interface communications links be available as an operational backup mode. No significant Tug/Orbiter checkout operations are planned to be performed by the Orbiter crew during this time because 1) crew ingress occurs after the majority of prelaunch tests and propellant loading operations (T-45 minutes), and 2) the Orbiter's vertical position and the orientation of the crew seats make impractical any extensive use of the Orbiter payload support facilities located at the MSS/PSS. Therefore, the only actions required of the Orbiter crew during this time involve activation of the Tug real-time monitor software and

subsequent monitoring for Tug out-of-tolerance conditions or caution and warning indications. This operation is expected to take only 20 seconds of mission specialist time and involves a simple Orbiter CRT/keyboard operation.

During Orbiter ascent/descent, no Orbiter crew actions are required in support of Tug operations other than monitoring Tug caution and warning indicators. During this time period, the Tug real-time monitoring software (in the GPC) will monitor all Tug critical functions and will 1) indicate status to the crew (through CRT or CWE) in the event of anomalous behavior, and 2) cause activation of automatic corrective action sequences for selected anomaly types and situations. Identification of specific anomalies and the required corrective action was outside the scope of the current study.

During ascent and on-orbit operations, the Orbiter is given prime responsibility for caution and warning monitor and control operations, including initiation and execution of Tug abort sequences.

Tug and deployment adapter status and caution and warning parameters will be interleaved with Orbiter telemetry data and transmittal to Orbiter and Tug ground operations centers for processing during this and other flight-operational periods. The telemetered data will be immediately analyzed for out-of-tolerance conditions and subjected to trend analysis to predict potential flight or mission anomalies. Further non real-time processing of the data will be performed to aid Tug maintenance operations at the conclusion of the current mission.

The Tug/Oribter on-orbit category of operations contains five operational periods consisting of:

a. Predeployment operations.

b. Deployment operations.

c. Post deployment operations.

d. Precapture operations.

e. Capture operations.

During predeployment operations the Orbiters cargo bay doors are opened, Tug is activated, and the status of its operating systems is verified through simple tolerance checking of Tug and deployment adapter telemetry data. Any detailed or functional checkout required will be performed through Tug/Orbiter to ground RF data links. Before initiating deployment operations, a final predeployment status will be performed to verify that all Tug parameters, systems, valves, and actuators are in the correct deployment configurations.

The deployment sequence is initiated by arming the deployment adapter arm/safe switch to allow power application for capture latches and rotation actuators. The Orbiter then releases the forward support fitting latches, and D/A actuators are used to rotate the

Tug to its 35-degree removal position. The Tug RF communications system is activated and Tug/Orbiter RF communication is established and verified at this time. The Orbiter crew (PHS) then attaches the RMS to the Tug end effector socket and releases the D/A capture latches. Latch release includes a push-apart motion that disengages Tug to D/A alignment devices and electrical umbilicals. If the Tug payload requires the use of a Tug forward umbilical, the previous two steps must be preceded by retraction of that unit.

When the Tug and deployment adapter are disengaged by the capture latches, the Orbiter remote manipulation system (RMS) assumes full responsibility for Tug position and attitude control. RMS alignment, attachment, Tug positioning, and deployment adapter disengagement/insertion are performed using a computer-controlled man-in-the-loop operation with direct and TV-augmented monitoring. Each major segment of the operation has specific viewing procedures and control requirements associated with it. TV cameras mounted on the RMS wrist and deployment adapter structural shell provide the additional operator monitoring needed to oversee and adjust the preprogrammed insertion sequence.

Once the Tug clears the adapter, positioning continues under computer control with manual jog override until the desired Tub/Orbiter deployment positions are achieved. The Tug is then released, completing this operational phase.

Immediately following RMS release the Orbiter performs a backup maneuver with its nose-mounted axial ACS thrusters. After an initial Orbiter to Tug clearance is obtained (suggest 100 ft or 30 m), the Tug APS is armed by an Orbiter RF command executed through the mission specialist Tug control panel, which enables Tug attitude stabilization. When the 1-mile (1.85 km) separation is achieved, Tug control is transferred from Orbiter to ground. During the 1-mile (1.85 km) initial separation, and following ground handoff, the Orbiter has primary and backup RF control, respectively, of Tug APS and main propulsion systems through arm/safe switches located in the crew compartment. This backup capability should be limited to a Tug vicinity of 20 miles (37 km). Through an RF link, ground control then commands the Tug actual mission sequence to begin: extend engine nozzle, arm main Tug propulsion system, and start Tug mission sequence (GO TO FLIGHT). The Orbiter will have the capability to effect these commands (as a backup mode) in the event of ground facility problems or lack of ground communications coverage.

After Tug mission completion and Tug return to the Orbiter/Tug rendezvous orbit, the Tug ground operations cause the Tug to be safed through Tug/Ground RF data and command links. Safing operations include main propellant tank drain and vent, retraction of the main engine nozzle, main propulsion system safing, attitude holding through the APS, and status (safe for Orbiter retrieval) verification. After handoff has been accomplished, the Orbiter crew verifies the Tug safety status and performs the rendezvous maneuver.

During Tug/Orbiter capture operations the Orbiter approaches the Tug and positions its RMS within wrist extension distance (24 inches (61 cm)) of the Tug end effector socket. When this alignment is obtained, both the Tug and Orbiter auxiliary propulsions systems are turned off (Tug's through Orbiter RF command), the RMS is attached to the Tug, and the Orbiter RCS is re-enabled to maintain Orbiter attitude. The Orbiter program for retracting the Tug through automated RMS control under flight crew (PHS) supervision is then activated and the Tug is positioned into the Tug deployment adapter.

Insertion is completed by D/A capture latch engagement (under the control of the Tug deploy/capture panel), which draws the separation interface together and mates the safety critical (caution and warning) electrical umbilicals. Orbiter RF to hardwire communications handoff is verified, and the Tug plus deployment adapter is rotated 35 degrees back into the cargo bay followed by forward support fitting latch engagement and Orbiter verification of Tug status. The forward umbilical panel is re-engaged, +28V DC power supply transferred from Tug to Orbiter fuel cells, and the Tug fuel cells are shut down. Tug propellant tank safing and repressurization is accomplished through a GPC software program, which controls Tug and the abort helium supply located in the deployment adapter. The deployment adapter system (capture latches, rotary actuators) is safed for return by removing the power supply to these functions through the Tug panel arm/safe switch.

Orbiter/Tug descent and landing operations are primarily involved with monitoring the applicable Tug caution and warning functions and maintaining Tug propellant tank and tank MLI system pressures above ambient. No special Tug/Orbiter control and monitor operations are associated with the Orbiter after touchdown. After rollout, additional Tug propellant tank and insulation purging is accomplished using ground-supplied helium. Post-landing hydrogen venting, if required, is performed with the Orbiter in-flight relief until an appropriate GH_2 vent umbilical is attached to the Orbiter T-0 fuel panel disconnect. Safety monitoring capability during Tug removal is supplied from a deployment adapter attached ground power umbilical.

4.6.4.2 Tug/Orbiter Interface Operation. Tug/Orbiter interface control and monitor operations start and terminate with the Orbiter crew or the Tug support equipment located in the Orbiter crew compartment. This section discusses the operation of the various Tug/Orbiter avionics interfaces employed during flight operations: 1) normal control, 2) normal monitor, 3) caution and warning, and 4) safing/abort control.

The Tug/Orbiter flight operations described in Section 4.6.4.1 are monitored or controlled through an Orbiter multifunction CRT display system (MCDS) CRT and keyboard terminal located at the MSS through one of three Tug-unique control and monitor panels, or through the Orbiter-supplied payload caution and warning annunciator panel. Three Tug-unique panels were selected (as opposed to only one) for three reasons:

1. It was found that the aft crew cabin control and monitor functions fall into three main categories, a) those associated with Tug initialization, checkout, and RF

control operations, b) those associated with deployment and capture of the Tug and its spacecraft from the Orbiter, and c) those associated with Tug abort and safing operations.

2. These panels are functionally most convenient when located near the Orbiter work stations related to the Tug/Orbiter task being performed.

3. The use of Tug-unique panels aids the Orbiter crew effectivity (see crew effectivity analysis of Section 4.6.5) by simplifying repeatable, routine but error-prone operation to a flip of a switch. Note that all panel operations could be performed through CRT and keyboard control.

These three panels and the associated control and monitor functions are illustrated in Figures 4.6-9 through 4.6-11.

MISSION SPECIALIST STATION

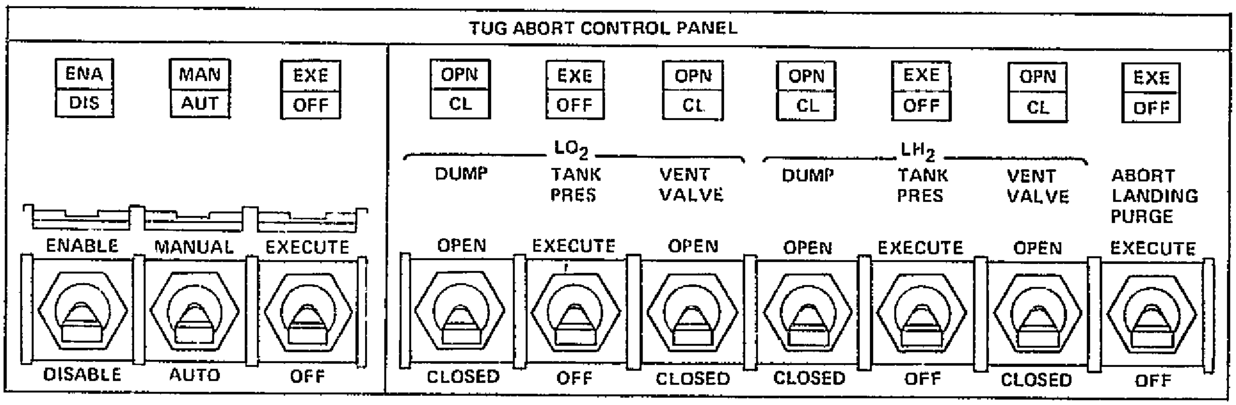


Figure 4.6-9. Tug Abort Control Panel

MISSION SPECIALIST STATION

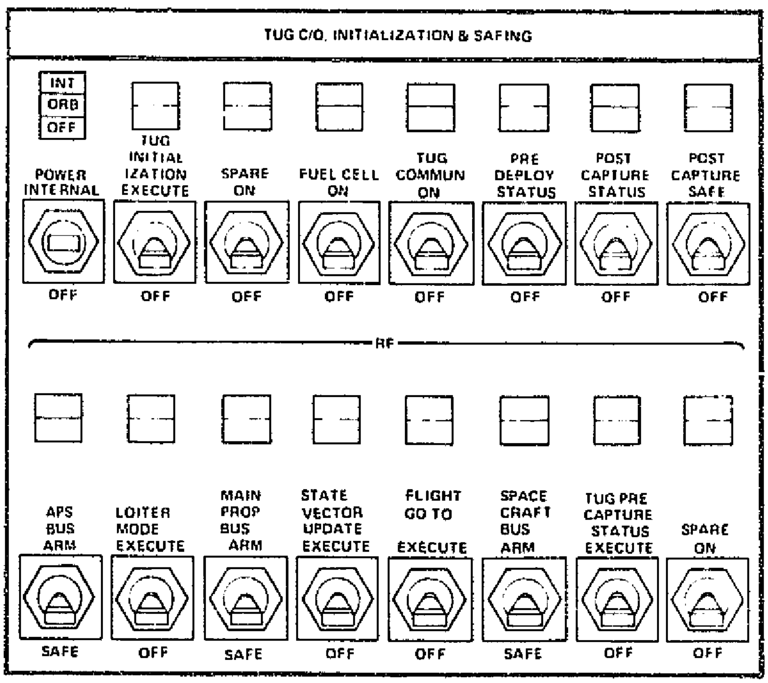


Figure 4.6-10. Tug Checkout, Initialization, and Safing Panel

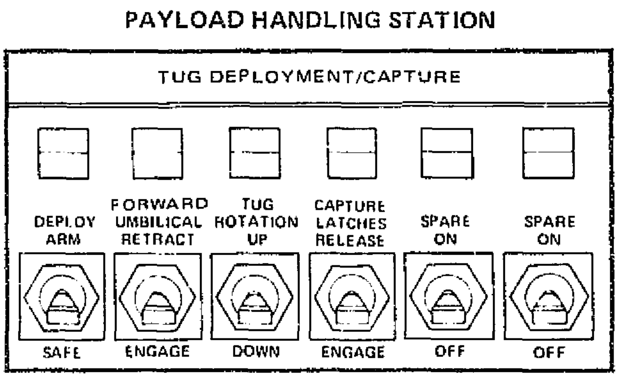


Figure 4.6-11. Tug Deployment/ Capture Panel

Tug deployment/capture functions are located at the payload handling station (PHS) near the aft window, and the initialization, C/O, and safing panel is located near the MSS CRT displays. The abort control panel is also located at the MSS but positioned such that the mission specialist has easy access to it during the Orbiter ascent mission phase. In general, the switch functions shown are arranged such that their operation proceeds from left to right and the indicated function is executed when the switch is in the up position. Two status lights (low-power led type) are shown above each function switch to indicate function status (function initiated – red, function complete – green). The operation of these panels, as well as the operation of the Orbiter MCDS and the Orbiter C&W and payload support equipment to effect Tug/deployment adapter control, is discussed below.

Normal Control and Monitor. The Tug/spacecraft to Orbiter control and monitor interfaces used for normal in-flight operational phases are shown in Figure 4.6-12. Tug telemetry data (through PSP units) and deployment adapter serial data is input to the PDI, where it is decommutated and stored into 2048 x 16 bit PDI buffer memory units. The contents of this memory is transmitted on demand to the active PCM master unit, where the data will be interleaved into the Orbiter 128 kbps downlink, placed onto Orbiter tape recorders, or made available to the Orbiter's GPC system through one of the five redundant data bus systems connecting the two PCM master units to the five GPC computers.

Access to PCM telemetry data is controlled by GPC operating system software, which both requests data from the master PCM units and loads (updates) the data in payload-dedicated rapid-access memory locations within the GPC system. Tug-unique control and monitor software would access this same telemetry table to verify Tug/deployment adapter status and to monitor the results of previous commands or to monitor Tug/deployment adapter caution and warning parameters.

All commands transmitted to the Tug or the deployment adapter will emanate as a result of Tug and/or Orbiter software control. Ground-generated RF commands are received by the Orbiter S-band communication system, processed in the GPC system, and routed to the Tug or deployment adapter in a 2k baud serial format through the appropriate Orbiter payload MDM, PSP, and PI units. In a like manner, other Tug or deployment adapter commands are generated by Orbiter or Tug-support software associated with the GPC system.

Tug support software is activated in one of three ways: 1) by the Orbiter crew via the Tug-unique control panels located at the MSS and payload handling stations, 2) by the

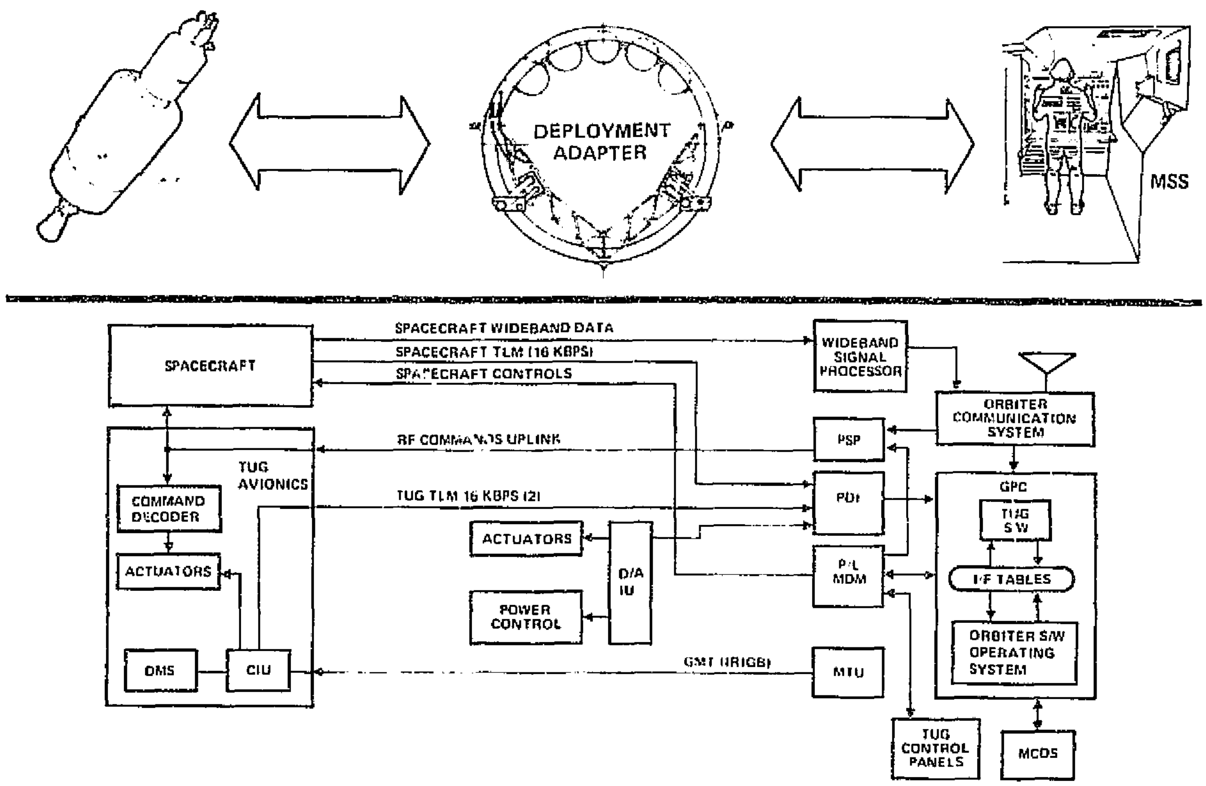


Figure 4.6-12. Normal Tug Control/Monitor Interface

Orbiter's MCDS display and keyboard units located at the MSS, or 3) by automatic Tug safing software programs activated by the Tug caution and warning monitor programs. As indicated above, normal routine operations that occur in sequence for each Tug mission are initiated by switches located on the Tug control panels. Each switch output is connected to one of the discrete input channels associated with the payload MDM unit. The change of state associated with the panel switch operation will be monitored by the Orbiter GPC software, which will detect the change of state and update a data table in memory. Periodic scanning of this table by Tug-unique real-time monitor software in the GPC will detect change of state (pseudo priority interrupt) and cause execution of the appropriate Tug application program to accomplish the desired task.

An example of this type of operation is the Tug initialization command. Operation of the Tug initialization switch by the mission specialist will cause a discrete input to the P/L MDM to activate Tug support software in the GPC. In this case the Tug initialization software will format a command to be transmitted to the Tug DMS (through the PSP), telling the Tug DMS to execute its initialization sequence. The GPC initialization software will then monitor the progress of the Tug initialization through the Tug telemetry downlink (through the PDI). This action causes a red light above the control panel switch to light, indicating the desired action has started. Any anomalies associated with the planned initialization sequence or status messages will be displayed to the mission specialist through the MSS CRT display unit.

When the Tug initialization sequence is successfully completed and verified, the GPC software will cause a green light associated with the Tug control panel switch to light from a discrete output command from the P/L MDM, then terminate. A program flag in memory associated with the program successful termination will then allow the next task in the deployment/capture operating procedure to be activated.

An additional data link is used to transmit GMT timing data to the Tug DMS from the Orbiter MTU. This data will be transmitted in a standard IRIG-B digital format and is decoded by the Tug avionics to provide the Tug with synchronized timing accurate to one ms.

Operation Support Software. Tug unique software associated with the Orbiter GPS system required to support the recommended baseline interface concept control and monitoring operations is shown in Table 4.6-13. The five categories of programs listed include a preliminary estimate of software characteristics such as processor memory size, data base size, average response time (time from program initiation until completion), and relative program complexity. To aid determining software development cost, the complexity of each software program was identified by an alpha-numeric code indicating both the degree of past experience associated with the software task as well as its relative level of difficulty. This code is shown below:

First Letter	Second Numerical
A. We have done this task before	1. Simple (non-real time)
B. We have done a similar task before	2. Easy (simple but real-time)
C. New task, no previous experience	3. Average
	4. Complex
	5. Difficult

In addition to software characteristics, Table 4.6-13 indicates the primary (P) and backup modes (S, T) of causing execution of each program and the Orbiter control location. The operational phases during which each program would normally be executed are also shown.

Baseline software services and programs available from the Orbiter are listed below:

a. Memory. 10,000 32-bit words are offered by the Orbiter for payload use.

   1. Half word instructions are permitted – (thus, two instructions could be packed into one 32-bit word).

   2. Math library services are provided (square root, sine, cosine) external to the 10,000-word allocation.

Table 4.6-13. Tug/Orbiter Software for Ascent, Deployment and Capture

Option	Software Option Name/Function	Orbiter Control Location				Software Characteristics					Operational Phase		
		Abort Control	Deploy Panel	Initialize C/O Safe	KB CRT	Memory Req.	Data Base	Speed Kops (avg)	Response Time	Complexity	Ascent/ Descent	Pre-Deploy	Deploy/ Capture
	<u>Tug Caution, Warning and Abort Options</u>												
101	Execute Tug Critical Function Status Monitor				P	700	100	0.3	1 sec	B-2	A, D	P	D, C
102	Execute Tug Abort Mode 1 or 2, x	P, T			S	150	50	1.0	0.1 sec	C-3	A	P	
	<u>Tug Initialization, Checkout</u>												
201	Execute Tug Initialization			P	S	500	200	0.01	30 min	B-4		P	
202	Execute Tug State Vector, Update			P	S	200	200	0.033	1 min	B-3		P	
203	Execute Command Tug Fuel Cell ON/OFF			P	S	20	5	0.02	1 sec	B-2			D, C
204	Execute Command Tug Communications ON/OFF			P	S	20	5	0.02	1 sec	B-2			D, C
205	Execute Tug Predployment Status Check			P	S	2000	500	0.03	1 min	B-3		P	D
206	Execute Tug Post Capture C/O			P	S	2000	500	0.03	1 min	B-3			C
207	Execute Tug Post Capture Safing			P	S	150	50	0.003	1 min	B-3			C
	<u>Tug Deployment/Capture Options</u>												
301	Execute Deploy Arm/Safe Switch to xxxxx		P		S	40	50	0.01	30 sec	B-2			D, C
302	Execute Retract/Engage Fluid Umbilical		P		S	40	10	0.01	30 sec	C-2			D, C
303	Execute Rotate D/A Up/Down xxxxx		P		S	40	10	0.01	2 min	C-2			D, C
304	Execute Retract/Engage Electrical Umbilical		P		S	40	10	0.01	30 sec	C-2			D, C
305	Execute Engage/Release Capture Latches		P		S	40	20	0.01	30 sec	C-2			D, C
	<u>Tug RF Control Options</u>												
401	Execute APS Arm/Safe and Switch to xxxxx			P	S	45	100	0.01	30 sec	C-3			D, C
402	Execute Main Propulsion Arm/Safe Switch to xxxxx			P	S	45	100	0.01	30 sec	C-3			D
403	Execute Tug Loiter Mode			P	S	45	100	0.1	2 sec	C-3			D
404	Execute State Vector Update			P	S	45	100	0.01	30 sec	C-3			D
405	Execute Go to Flight Command			P	S	45	100	0.1	2 sec	C-3			D
407	Execute Precapture Safing			P	S	2000	100	0.033	1 min	C-3			C
	<u>Tug Control and Utility Options</u>												
501	Execute Switch to Orbiter Power			P	S	20	5	0.01	2 sec	B-2		P	
502	Execute Switch to Tug Internal Power			P	S	20		0.01	2 sec	B-2		P	
503	Execute Switch Tug Power OFF			P	S	20		0.01	2 sec	B-2		P	
504	Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)				P	65	300	0.5	2 sec	B-2		P	
505	Execute Output Tug-D/A Control Status				P	250	300	0.5	2 sec	B-2		P	
506	Execute Load Tug DMS Loc xxx with xxx				P	45	10	0.4	1 sec	B-2		P	
507	Execute Read Tug DMS Loc xxx with xxxxx				P	45	10	0.4	1 sec	B-2		P	
508	Execute Display Tug TLM xxx continually				P	40	500	0.4	1 sec	B-2		P	
	<u>Miscellaneous Tables</u>					1500					A,D	P	D,C

b. PCM Data Input. This function inputs the telemetry words to the payload software from the telemetry data streams. Software use requirements are to provide a measurement list and sample rate for each measurement.

c. Tolerance Checking Software. Needs data tables as input, effectively listing measurement to be tolerance checked, and its high/low limit range. More than one consecutive tolerance violation is required to trigger a display comment. Selected variable time variable tolerance limits are permitted.

d. Display overhead and servicing software is available, (i.e., keyboard interfacing software, CRT driver software, are provided). Display superstructure software is estimated to require 200 32-bit words per page. Only data to be displayed need be input to this superstructure. Mass memory provisions for up to 20 payload-unique display pages is provided. A mass memory display page can overwrite the current display page in resident GPC memory.

e. Preprogrammed command sequences can be stored in an MDM PROM and called from the payload software with one or two commands. Each PROM allows storing of up to 512 command words. In effect, this feature allows selected (repeated) command routines to be called as subroutines.

Considering the services offered, and matching them against Orbiter/Tug support software needs, it is concluded that the Tug/Orbiter checkout software requirements can be easily met.

Orbiter Caution and Warning Interface. The philosophy used in the caution and warning system is that caution and warning indication should be used only when a threat to the safety of the Orbiter or crew manifests itself and immediate crew action is required. Implicit in this philosophy is the requirement that the crew must have available to them some action that will counteract the hazard. The caution and warning functions for the Tug were identified through review of failure modes and effects analysis (FMEA) and hazard analyses. The caution and warning philosophy and the FMEA are described in detail in Section 4.7 of this volume.

A Tug caution and warning philosophy of alerting the Orbiter crew only during periods of anomalous Tug or Deployment Adapter operation is recommended. Thus, during normal in-flight operations the Tug master caution, master warning and Orbiter C&W panel indicators would not be illuminated. In addition, the MSS CRT display would present no Tug caution and warning information.

The safety of the Shuttle and its crew is ensured during both Tug attached and detached modes by providing appropriate crew Tug caution and warning indicator in a timely and reliable manner. The caution and warning indicators recommended consist of a master Tug caution, a master Tug warning and provisions for five specific warning indicator functions on the payload warning indicator panel. It is suggested that these indicators be grouped and located on the aft-facing instrument panel at the forward

side of the mission specialist station (within view of the mission specialist during ascent operations). In addition to these caution and warning indicators, use of the MSS CRT and keyboard is recommended for display of detailed caution and warning data and corrective action aids.

During operational phases when the Tug is attached to the Orbiter, two operationally redundant communication paths are used to transmit the ten Tug and seven deployment adapter caution and warning measurements to the Orbiter. During detached operations (deployment and capture), continuous monitoring of Tug and spacecraft C&W functions is maintained through the Tug/Orbiter RF telemetry link. Tug antenna loading and the final rotation angle will be designed such that this link may be established and verified after Tug rotation but before retraction of the Tug deployment adapter umbilicals.

For warning signals the primary path is implemented by hardwiring the output of the three Tug warning sensor parameters (N_2H_4 pressure, LO_2 tank pressure, and LH_2 tank pressure) directly to the Orbiter caution and warning electronics unit as shown in Figure 4.6-13. Annunciators associated with single or multiple combinations of inputs to this unit will be activated when the input signal characteristics exceed either high or low out-of-tolerance levels (98 increments of approximately 50 mv steps between 0.1 and 5 Vdc).

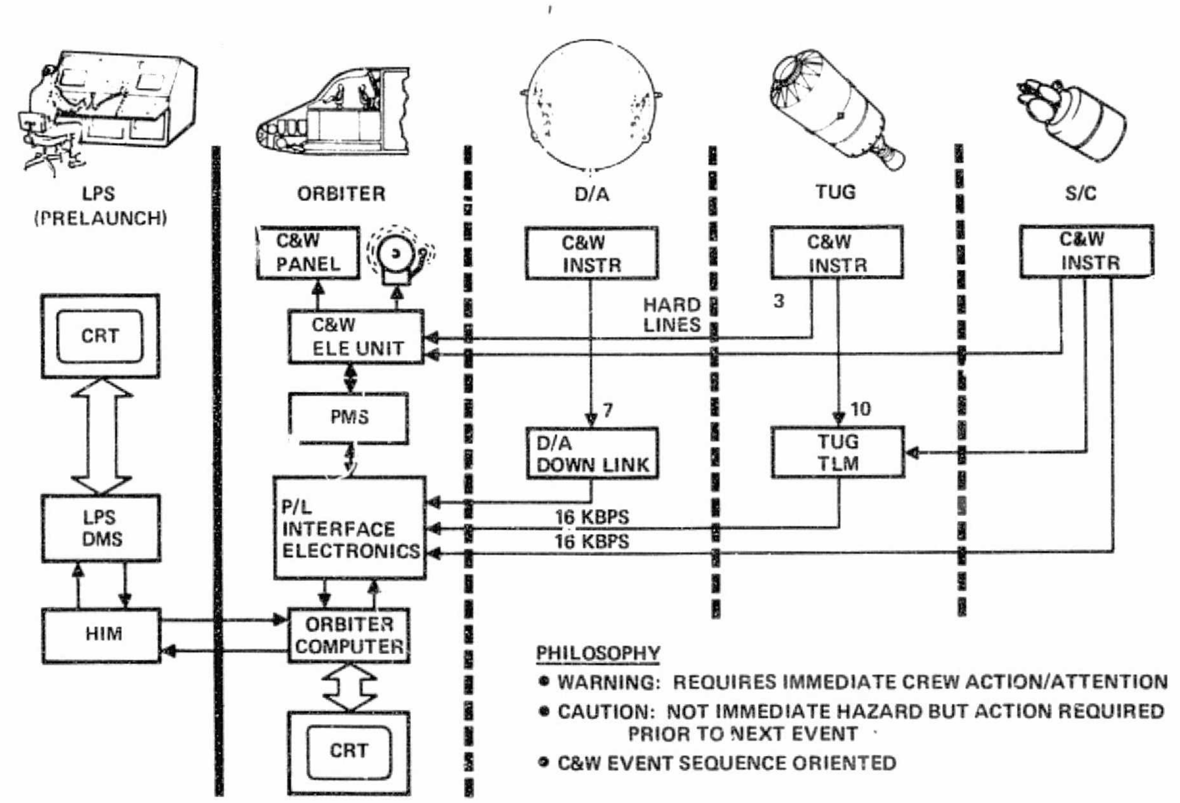


Figure 4.6-13. Tug Caution and Warning Monitor Interface

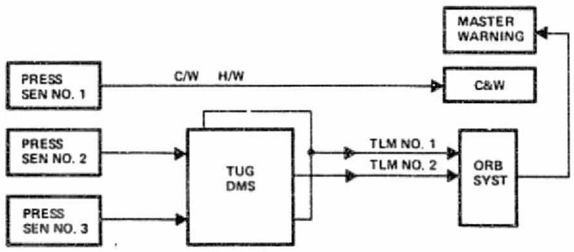


Figure 4.6-14. Typical Tug Warning Implementation

In the secondary path for transmitting Tug warning signals to the crew, the warning data from separate sensors is multiplexed onto the Tug telemetry data stream and transmitted to the crew through the PSP/GPC/MSS CRT display equipment, Figure 4.6-14. Tug and Orbiter C&W software will allow the crew to further monitor the anomaly and relate its cause. It should be noted that no warning functions associated with the deployment adapter have been identified.

Warnings result in 1) illumination of the master warning light, 2) illumination of a specific warning light, 3) continuous sounding of the warning tone, and 4) an indication on the CRT of the warning condition and the crew action to be taken. The master warning and the warning tone can be reset to OFF, but the specific warning light and the CRT display will remain active until the hazardous condition is actually cleared.

The crew visual alert indicators for a typical Tug warning anomaly are shown in Figure 4.6-15. When the warning condition causing the alert is detected by the Orbiter avionics (C&W electronics or TLM/GPC), the master caution indicator will

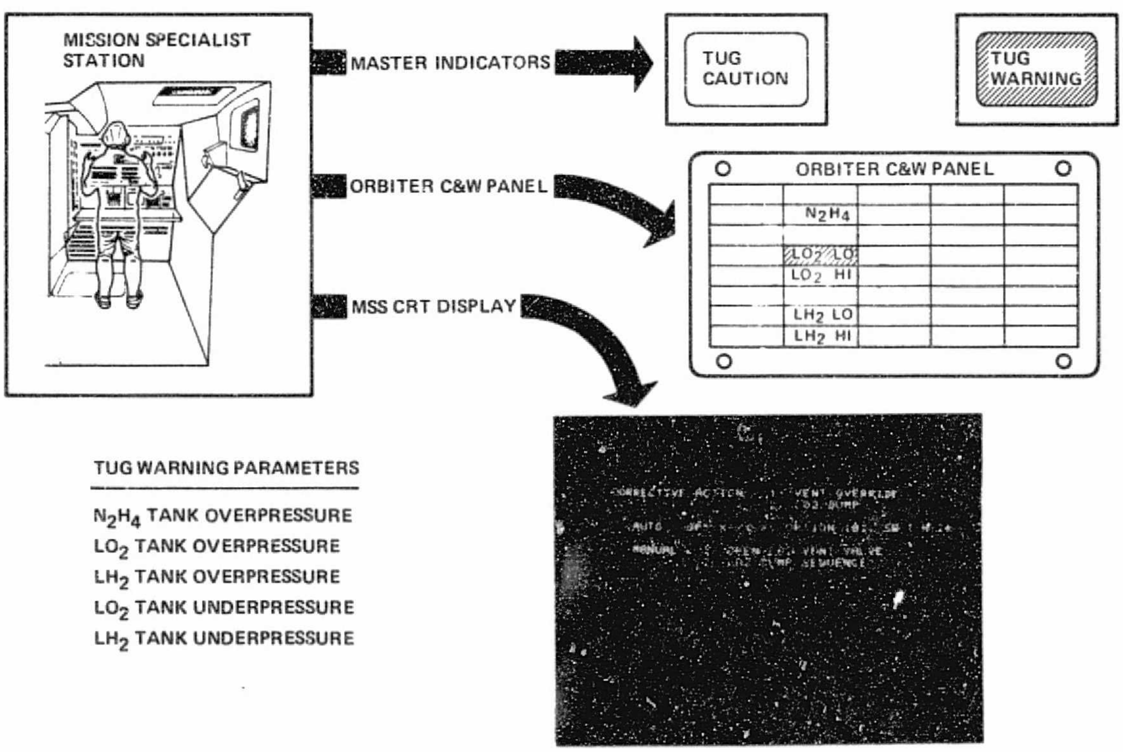


Figure 4.6-15. Tug Caution and Warning Crew Alert for Warning Condition

be illuminated, the specific Tug warning lamp on the Orbiter C&W panel located at the MSS will be illuminated, and a GPC-generated message describing the specific anomaly and corrective action information will be displayed on the MSS CRT display. The corrective action message would include the manual operation available to correct the problem as well as identification of the CRT page code (OPS X-XX-X) associated with the Tug-unique Orbiter software programs required to investigate or correct the anomaly under computer control.

In the example illustrated, the software programs on the CRT page referenced by the display OPS X-XX-X code might: 1) allow control of the Tug vent valves, 2) initiate an LO_2 propellant dump sequence, 3) allow verification of the LO_2 system status, or 4) present the LO_2 tank pressure history for the past five minutes.

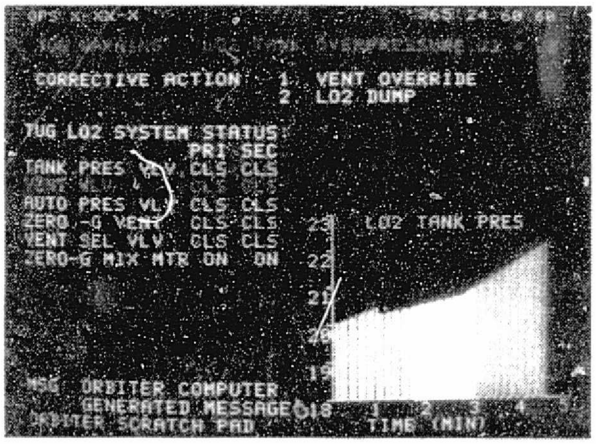


Figure 4.6-16. Typical MSS CRT Format to Investigate "Warning" Alert

The CRT format of Figure 4.6-16 represents typical data that might be displayed on the MSS CRT as the Orbiter crew investigates an anomaly causing a Tug warning alert. In the case illustrated, the results of two Tug-unique software programs located in the Orbiter GPC system are shown. On the left side of the CRT, the Tug LO_2 system status is displayed indicating that both (primary and secondary) Tug LO_2 tank vent valves are closed. This system status data also indicates that other valves and actuators associated with the Tug LO_2 system are in the proper configuration.

On the right side of the CRT, a 5-minute plot of the LO_2 tank history is displayed (updated once a second). This histogram would indicate that one normal operation cycle of the Tug LO_2 vent valves occurred (between times 0 and 1.7 on chart) before anomalous operation began and that the LO_2 tank pressure was rapidly approaching a danger level.

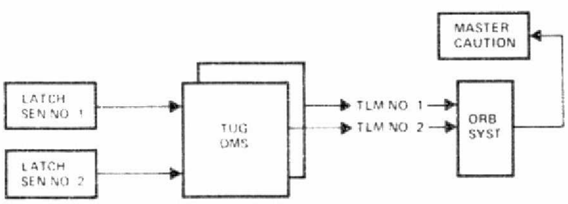


Figure 4.6-17. Typical Tug/Deployment Adapter Caution Implementation

As indicated in Figure 4.6-17 the seven Tug and seven deployment adapter caution measurements will be transmitted (in a redundant manner) in the respective TLM downlinks. Cautions result in 1) illumination of the master caution light, 2) intermittent sounding of the warning tone, and 3) an indication on the CRT of the caution condition and the crew action to be taken. The master caution light and the warning tone can be reset to OFF, but the CRT display will remain active until the potentially hazardous condition is cleared.

The crew visual alert indicators for a typical Tug caution anomaly are shown in Figure 4.6.4-11. When a caution condition is detected by the software program monitoring Tug/deployment adapter TLM data, the Tug master caution indicator will be illuminated (under software control) from an output from the payload MDM. In addition, a message describing the specific problem and corrective action information will be displayed on the MSS CRT display. The corrective action data displayed would include the manual operation available to correct the problem (if any), as well as identification of the unique CRT page code (OPS X-XX-X) associated with the investigation or automatic corrective action for the specific caution anomaly. In the case illustrated in Figure 4.6-18, the CRT page referenced by the OPS X-XX-X code might allow: 1) the operator to execute a software program to activate the deployment adapter switch (D/A-E-17) to disarm the deployment adapter, or 2) verify the deployment adapter status through another program.

The data in Figure 4.6-19 indicates typical data that might be displayed on the MSS CRT as the Orbiter crew investigates an anomaly causing a caution alert. In the case illustrated, the mission specialist has caused execution of a Tug-unique software program located within the Orbiter GPC system to determine the deployment adapter status.

It is felt that Orbiter crew effectiveness will be enhanced and problem recognition and solution time will be reduced if color displays are made available for payload operations. A suggested color scheme is to use: 1) red for caution and warning messages,

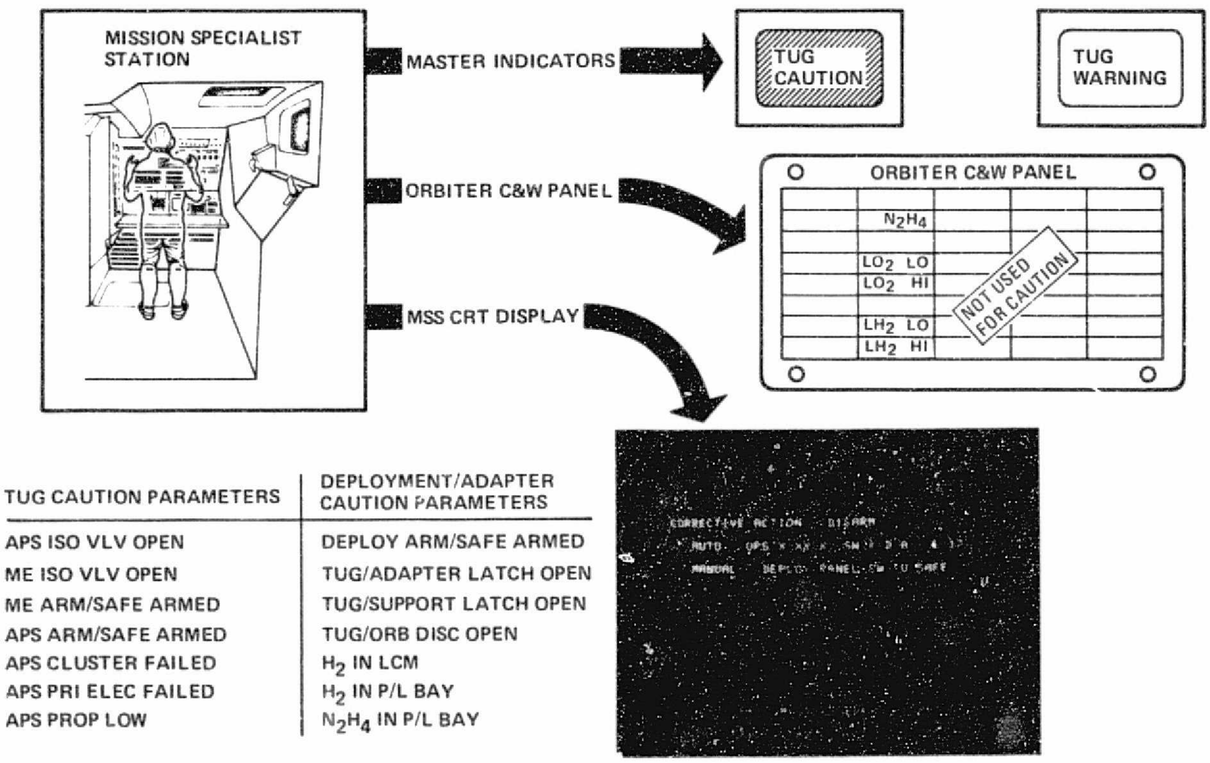


Figure 4.6-18. Tug Caution and Warning Crew Alert for Caution Condition

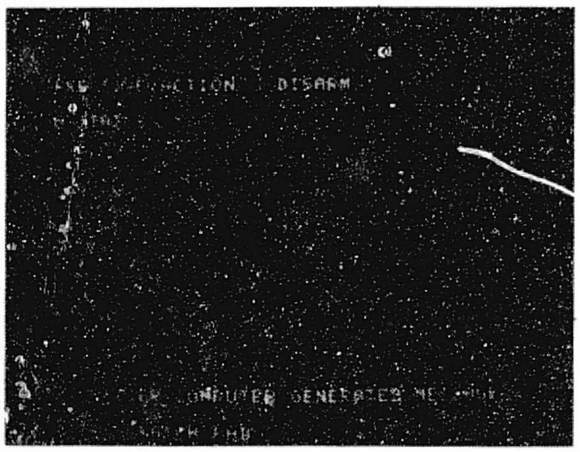


Figure 4.6-19. Typical MSS CRT Format to Investigate Caution Alert

out of tolerance indication, and undesired status indication, 2) yellow to indicate corrective action messages, and 3) green to indicate normal conditions and normal display operations messages.

Tug/Orbiter Abort and Safing Interface Operation. A Shuttle abort may result from either a cargo or Shuttle system anomaly or malfunction. If a safety critical Tug out-of-tolerance condition is detected and the appropriate corrective action measures are unsuccessful, an abort dump of Tug propellants may be required.

Three operational methods of executing safing and abort commands are available to the Orbiter crew and the ground-based Tug. The primary technique consists of initiating safing or abort sequences by Tug abort panel switches, causing execution of a Tug software support program to transmit the associated uplink commands to the Tug DMS through the CIU). The Tug DMS would then activate the proper Tug actuator(s) and verify that the proper abort activity occurred. The associated Orbiter support S/W program would verify the action by monitoring Tug telemetry data. Two backup modes ensure abort operations through either an MSS/PSS automatic sequence or, if necessary, the MSS operator can execute the abort controls manually. Three abort control switches allow control of abort enable, manual versus automatic operation, and the abort execution command. The abort enable switch ensures that at least two switch operations are required to initiate the abort sequence thus limiting the probability of an inadvertant crew initiated abort.

If the manual abort mode is selected, seven additional switches allow control of the individual abort operations. To effect the dumping of Tug LH_2 and LO_2 propellants, suitable settling thrust must be provided to orient the propellants over the tank drain outlets. Orbiter thrust availability is dependent on the mission phase during which abort is initiated. For early aborts, return to launch site (RTLS) and abort once around (AOA), sufficient settling thrust and duration are provided by the Space Shuttle main engines (SSME) or orbital maneuvering system (OMS) for dump completion. For later aborts, abort to orbit (ATO) or abort from orbit (AFO), the Orbiter has insufficient propellant quantity and settling thrust to provide orientation from dump initiation to propellant depletion. To obtain complete dump during these abort modes, Tug propellants are exhausted axially at the Orbiter dump ports to provide settling thrust during the intermediate dump period. Orbiter OMS or RCS thrust is used at dump initiation and termination for settling orientation and residual reduction, respectively.

During detached operations, the Orbiter crew and ground stations have the capability of safing the Tug through RF control using the standard Tug RF uplink system and

command decoder units (redundant also). Normal RF safing commands transmitted by the Orbiter are the APS arm/safe commands, used to enable or disable the Tug APS system during deployment/capture operations, and the loiter mode command, used to direct the Tug to assume a safe stable condition (APS system on, main propulsion system off.) The Tug/Orbiter interfaces associated with the Tug safing and abort operations are shown in Figure 4.6-20.

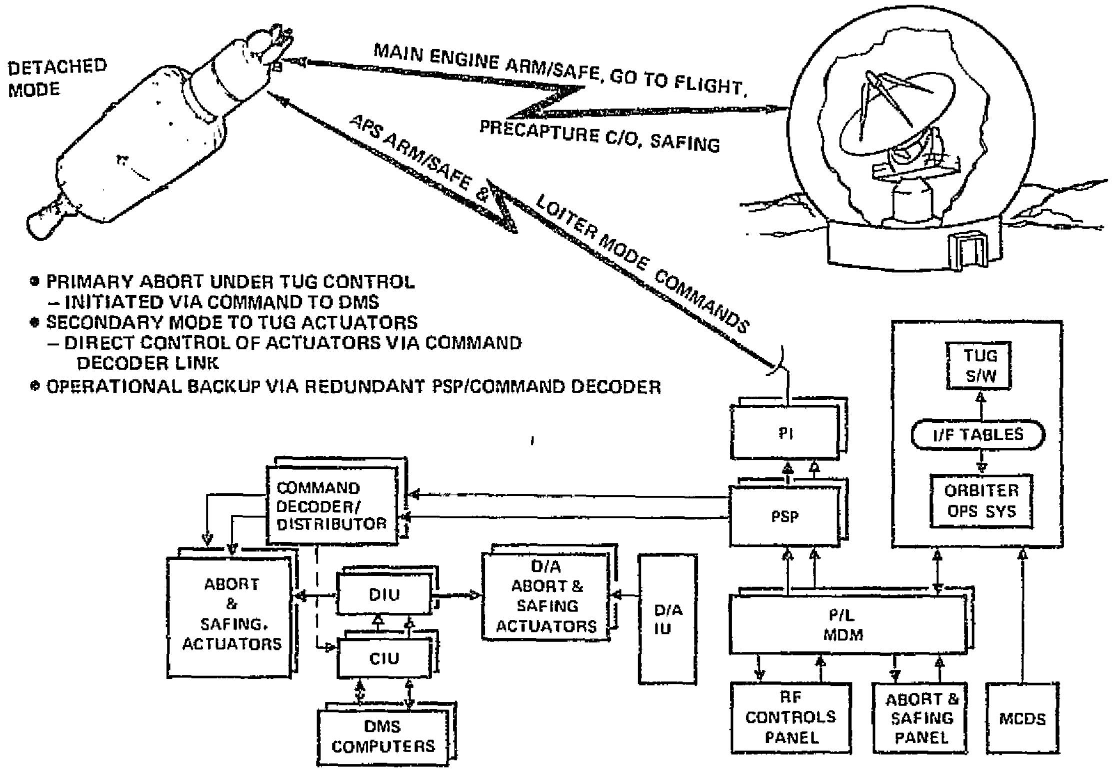


Figure 4.6-20. Tug Safing and Abort Operations and Interfaces

4.6.5 CREW EFFECTIVITY/MAN-MACHINE INTERFACE. A crew effectivity/man-machine interface analysis was conducted to assess the ability of the Orbiter crew to perform the interface functions necessary for Tug monitor and control. In this study the analysis consisted of two main parts:

a. Analysis to determine concept validity (i.e., can the crew member at the appropriate Orbiter crew station accomplish the required tasks within the limits of available operation time, physical ability, and operational complexity.

b. Analysis to determine the degree of manual (crew controlled) versus automated control and monitoring of Tug operational functions.

Crew Effectivity Analysis. In performing the crew effectivity analysis, a timeline was developed for a geosynchronous placement and return mission. Crew activities were assigned and task durations established for the recommended baseline implementation concept. Crew task time requirements were summed per mission phase and compared with the time available to accomplish the tasks. The results, which are summarized in Table 4.6-14, show that with a three-man Orbiter crew, more than adequate time is available to accomplish the required tasks during all normal mission phases. (Orbiter/Tug abort timelines were not considered in this analysis.) In this table, time available for crew operations is shown in parenthesis under each mission phase heading followed by required crew times for the mission specialist, pilot, commander, and payload specialist.

It should be noted that only one crewman is required for Tug monitor and control operations for all mission phases except deployment and capture, and that the total time required for Tug activities is 4.5 manhours out of a total of 55.8 for a three-man crew. The duties of the mission specialist were separated into two categories corresponding to: 1) tasks that are the dedicated responsibility of the mission specialist, and 2) tasks that could be performed by a payload specialist (if necessary).

This separation of duties was performed to determine the task mix ratio between the mission specialist and a Tug payload specialist (if one were employed). The results indicate that mission specialist duties require approximately 33 minutes compared with 66 minutes of Tug monitor and control oriented duties. Most important, however, the results indicate that during periods when a mission specialist would be busy, the payload specialist would be idle (and vice versa). Furthermore, unless the payload specialist had other duties pertaining to the Tug's spacecraft, he would be required for only 66 minutes out of an 18.6 hour mission.

It is therefore recommended for Tug missions that the mission specialist be trained in Tug flight operations and that the payload specialist function (if required) be dedicated for the Tug's spacecraft operations. Other arrangements supporting this conclusion are based on the fact that Tug payloads occupy approximately 40 percent of

Table 4.6-14. Orbiter Crew Activity Summary

Crewman	Operation (Hr:Min:Sec)	Prelaunch (45 Min)	Ascent (10 Hr, 32 Min)	Deploy (1 Hr, 16 Min)	Return/ Capture (5 Hr, 43 Min)	Descent (20 Min)
Mission Specialist	C&W & RF Comm Tug Control/Monitor	0:20 / 0:00 } 0:20	0:05 / 30:05 } 30:10	2:00 / 34:00 } 36:00	31:30 / 0:00 } 31:30	0:00 / 2:00 } 2:00
Pilot	Deployment/Capture	0:00	0:00	41:00	58:00	0:00
Commander	Vehicle Control	0:00	0:00	9:00	43:00	0:00
P/L Specialist	No task	0:00	0:00	0:00	0:00	0:00

Orbiter flights. Thus training of a limited number of mission specialists to perform Tug deployment and capture duties will probably be easier and more cost effective than training Tug specialists to be familiar with many diverse spacecraft functions; or worse, qualifying a large number of spacecraft specialists to perform Tug deployment duties. The detailed data from which the results of Table 4.6-14 were obtained is presented in Table 4.6-15. This table separates each mission phase into the individual mission events required and identifies the vehicle affected, event start/stop times, crew member involved, and Tug/Orbiter support software required.

Man-Machine Interface. Analysis of the crew man-machine interface environment was also conducted to determine a recommended concept for: 1) the degree of manual control versus crew automated support, and 2) types and locations of crew display and control devices. This analysis was conducted with respect to limits of crew physical ability, response time operational complexity, crew training requirements, and data access requirements.

The recommended launch and on-orbit positions of the commander, pilot, and mission specialist are indicated in Figures 4.6-21 and 4.6-22.

During prelaunch activities, the crew will be constrained to a reclining position by the launch attitude of the Orbiter, thus it is recommended that Tug activities performed during this period be restricted to executing a small number of Orbiter software options to perform C&W monitoring and Tug status verification through the Orbiter CRT display system.

During Orbiter ascent the crew will be exposed to 3g acceleration loads, limiting Tug mission specialist physical activity required to operate control panel switches to forward (±45 degrees lateral) reach locations, which do not require forward body lean. Monitoring activity during this period will be somewhat less restricted in that the Tug mission specialist will have sufficient head and neck movement capability to observe both the forward bulkhead of the mission specialist station and the CRT and control panels located at the MSS to his right. During ascent, therefore, it is recommended that the Tug/spacecraft caution & warning annunciators be located forward of the mission specialist on the forward bulkhead of the MSS, and that backup C&W information be automatically displayed on the MSS CRT display to the mission specialist's right-hand side.

During on-orbit operations, including Tug deployment and capture, the crew has greater liberty to move about the Orbiter cabin. Control and monitor interfaces may be designed and located to facilitate each crewman's task. For Tug deployment it is recommended that the commander maintain control of the Orbiter (through the aft vehicle control station) while the pilot controls Tug deployment through the remote manipulator station and a Tug deployment control panel. Mission specialist duties would include execution of the control for arming and safing the deployment adapter

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Min	Sec	Event Duration Hr	Min	Sec	Elapsed Time Hr	Min	Sec
1.0.0	Prelaunch Operations	G/T				-2	0	0	2	0	0	0	0	0
1.1.0	Power Data Mgt. and Comm.	G/T				-2	0	0	0	0	0	-2	0	0
1.2.0	LO_2, LH_2 Tank Chilldown	G/T				-2	0	0	0	10	0	-1	50	0
1.3.0	Insulation, Membrane Purge	G/T				-1	50	0	2	0	49	0	10	49
1.4.0	LO_2 Slow Fill	G/T				-1	50	0	0	10	0	-1	40	0
1.5.0	LH_2 Slow Fill	G/T				-1	50	0	0	13	0	-1	37	0
1.6.0	LO_2 Fast Fill	G/T				-1	40	0	0	24	0	-1	16	0
1.7.0	LH_2 Fast Fill	G/T				-1	37	0	0	25	0	-1	12	0
1.8.0	LO_2 Slow Fill	G/T				-1	16	0	0	4	0	-1	12	0
1.9.0	LH_2 Slow Fill	G/T				-1	12	0	0	5	0	-1	7	0
1.10.0	Propellant Utilization Check (Qty. 1T06)	G/T				-1	5	0	0	1	0	-1	4	0
1.11.0	Continuous Fuel Replenishment	G/T				-1	5	0	1	3	45	0	1	15
1.12.0	Crew Entry	O/T				-0	45	0	0	15	0	-0	30	0
1.13.0	Initiate Caut. & Wng. Flt. Monit.	O/T	MS	101	Cont.	-0	30	0	0	0	20	-0	29	40
1.14.0	Subsystem Status Check	C/T				-0	5	0	0	2	0	-0	3	0
1.15.0	Secure Propellant Replenishment (Stop Topping)	G/T				-0	1	15	·0	0	15	-0	1	0
1.16.0	Termination Insulation Purge	G/T				-0	0	40	0	0	0	-0	0	40
1.17.0	Lock LH_2 and LO_2 Vent Valves	G/T				-0	0	40	0	0	20	0	0	40
1.18.0	Initiate Automatic Launch Sequence	Orbiter				-0	0	32	0	0	5	-0	0	27
1.19.0	Enable Thrust Vector Control Hyd.	Orbiter				0	0	0	0	0	0	0	0	0
1.20.0	Enable Arm/Safe Switch No. 1	Orbiter				0	0	0	0	0	0	0	0	0
2.0.0	Launch to Orbit	Orbiter				0	0	0	0	0	0	0	0	0
2.1.0	Liftoff	Orbiter				0	0	0	0	0	0	0	0	0
2.1.1	Begin Ascent Guidance - Pitchover	Orbiter				0	0	5	0	0	15	0	0	20
2.1.2	Roll Maneuver	Orbiter				0	0	6	0	0	25	0	0	31
2.1.3	Begin Gravity Turn - End Pitchover	Orbiter				0	0	20	0	0	0	0	0	20
2.2.0	Unlock LH_2 and LO_2 Vent Valves	Tug				0	1	50	0	0	0	0	1	50
2.3.0	SRM Burnout/Separation	Orbiter				0	2	5	0	0	0	0	2	5
2.4.0	Main Engine Cutoff	Orbiter				0	8	4	0	0	0	0	8	4
2.5.0	Jettison External Tank (Retrofire)	Orbiter				0	8	26	0	0	40	0	9	6
2.6.0	Achieve Initial Earth Orbit	Orbiter				0	8	49	0	3	11	0	12	0
2.6.1	OMS Burn	Orbiter				0	8	49	0	1	21	0	10	10
2.6.2	Lock LH_2 and LO_2 Vent Valves	Tug				0	10	19	0	0	1	0	10	20
2.6.3	Enable Zero-G Vent Devices	Tug				0	10	49	0	0	1	0	10	50
2.6.4	Terminate All Purges	Tug				0	10	49	0	0	0	0	10	49
2.6.5	Coast Operations	Orbiter				0	10	49	0	1	11	0	12	0
2.7.0	Cargo Initial Preparation	Orbiter				0	12	0	0	0	0	0	12	0
2.7.1	Release Cargo Bay Locks	Orbiter				0	12	0	0	0	30	0	12	30
2.7.2	Open Orbiter Cargo Bay Doors	Orbiter				0	12	30	0	1	0	0	13	30
2.7.3	Verify Electrical Power to Tug	O/T	MS			0	14	0	0	0	5	0	14	5
2.7.4	Activate Tug Initialization	O/T	MS	201	30 Min	0	15	0	0	30	0	0	45	0
2.7.5	Monitor Tug Critical Parameters	O/T	MS			0	16	0	0	0	5	0	16	5

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025) (Contd)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Min	Sec	Event Duration Hr	Min	Sec	Elapsed Time Hr	Min	Sec
2.8.0	OMS Burn (Transfer to 100×150 N.MI.)	Orbiter				0	41	14	0	1	52	0	43	6
2.9.0	Coast Operations	Orbiter				0	43	6	0	42	56	1	26	2
2.10.0	OMS Burn (Circularize at 150 N.MI.)					1	26	2	0	0	55	1	26	57
2.11.0	OMS Burn Complete					1	26	57	0	0	0	1	26	57
2.12.0	Update Guidance and Navigation					1	27	0	1	0	0	0	0	0
2.13.0	Coast Operations, Mission Dependent	Orbiter				1	27	0	9	19	0	10	46	0
3.0.0	Predeployment	O/T				10	46	0	2	0	0	12	46	0
3.1.0	Tug/Orbiter Status Checks	O/T				10	46	0	0	0	0	10	46	0
3.1.1	Checkout Manipulator Control Station	Orbiter	P			10	46	0	0	2	0	10	48	0
3.1.2	Release Manipulator Latches	Orbiter	P			10	48	0	0	1	0	10	49	0
3.1.3	Checkout Manipulator	Orbiter	P			10	49	0	0	5	0	10	54	0
3.1.4	Tug Status Check (Verify Tug/PL Readiness)	O/T	MS	205	1 min	10	46	0	0	10	0	10	56	0
3.1.5	P/L Status Check	O/PL												
3.2.0	Orient Orbiter for Tug Deployment	Orbiter	C			10	56	0	0	5	0	11	1	0
3.3.0	D/A Arm/Safe to Arm	O/T	P	301	30 sec	11	1	0	0	:	0	11	2	0
3.3.1	Align Tug IMU to Orbiter IMU (state vector update)	O/T	MS	202	1 min	11	2	0	0	1	0	11	3	0
3.3.2	Unlatch Tug Forward Attachment	O/T	P	302	30 sec	11	3	0	0	1	0	11	4	0
3.3.3	Retract Fluid Umbilicals	O/T												
3.3.4	Verify Adaptor Ready for Rotation	Orbiter	P, MS			11	4	0	0	1	0	11	5	0
3.3.5	Verify Tug/Payload Ready for Rotation	Orbiter	P, MS			11	5	0	0	1	0	11	6	0
3.4.0	Rotate Tug out of Bay	O/T	P	303	2 min	11	10	0	0	5	0	11	15	0
3.5.0	Perform Final Activation/Status Check	O/T	MS			11	15	0	0	0	0	11	15	0
3.5.1	Activate Fuel Cells	O/T	MS	203	1 sec	11	15	0	0	2	0	11	17	0
3.5.2	Activate Tug/Orbiter RF Links	O/T	MS	204	1 sec	11	17	0	0	3	0	11	20	0
3.5.3	Switch from Orbiter to Tug Power	O/T	MS	502	2 sec	11	20	0	0	1	10	11	20	10
3.5.4	Tug/PL Status (Final Go Ahead)	G/Orb.				11	20	0	0	10	0	11	30	10
3.5.5	Disconnect Ele. Umbilicals	O/T	MS	304	30 sec	11	32	0	0	1	0	11	33	0
3.5.6	Verify Tug/Payload Ready for Deployment	G/Orb.	MS			11	35	0	0	10	0	11	45	0
3.6.0	Connect Manipulator to Tug	Orbiter	P			11	36	0	0	5	0	11	41	0
3.7.0	Disengage Deployment Adaptor Capture Latches	Orbiter	MS	305	30 sec	11	41	0	0	5	0	11	46	0
3.8.0	Deploy Tug	O/T												
3.8.1	Extend Manipulator	Orbiter	P											
3.8.2	Verify Tug Communication RF Uplink	O/T	MS	401		11	54	0	0	1	0	11	55	0
3.8.3	Release Tug from Manipulator	Orbiter	P			11	55	0	0	0	10	11	54	10
3.8.4	Orbiter APS Burn – Sep to Safe Distance	Orbiter	C	401	30 sec	11	56	0	0	6	0	11	56	30
3.9.0	Verify Tug Attitude Control (Visual)	O/T	P, C			11	59	0	0	2	0	12	01	0
3.10.0	Estab. Gnd-Tug RF Link, Control	G/T	Gnd			11	56	0	0	2	0	11	58	0
3.11.0	Retract and Stow Manipulator Arm	Orbiter	P			11	56	0	0	5	0	12	1	0

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025) (Contd)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Min	Sec	Event Duration Hr	Min	Sec	Elapsed Time Hr	Min	Sec
3.12.0	Retract and Stow Deployment Adaptor	Orbiter	P	303	2 min	12	1	0	0	5	0	12	6	0
3.13.0	Safe Deployment Adaptor	Orbiter	P	301	30 sec	12	6	0	0	1	0	12	7	0
3.14.0	Enab/Activ Tug Main Prop Subsystem and Extend Nozzle (Automatic)	G/T (Orb.)	Gnd (MS)	(102)	30 sec	12	78	0	0	2	0	12	9	0
3.15.0	Perform Post-Sept. Tug Subsys Checks	G/T	Gnd			12	1	0	0	20	0	12	21	0
3.16.0	Transmit Tug Subsystems Checkout Data	Tug	Gnd			12	1	0	0	20	0	12	21	0
3.17.0	Verify Payload Ready for Phasing Injection	G/T	Gnd			12	21	0	0	1	0	12	22	0
3.18.0	Coast (Mission Dependent)	Tug				12	21	0	0	26	0	12	47	0
4.0.0	Mission (Geosyn Plcmt + Retrvl)	G/T				12	47	0	0	0	0	12	47	0
4.1.0	Phasing Orbit	Tug				12	47	0	0	0	0	12	47	0
4.1.1	Attitude Update	Tug				12	47	0	0	5	0	12	52	0
4.1.2	Position and Velocity Update	G/T (Orb.)	Gnd (MS)	(404)	30 sec	12	52	0	0	3	0	12	55	0
4.1.3	Go to Flight	G/T (Orb.)	Gnd (MS)	(405)	2 sec	12	55	0	0	2	0	12	57	0
4.1.4	Compute POI Burn Parameters	Tug				12	57	0	0	1	0	12	58	0
4.1.5	Verify MPS Ready for Burn	Tug				12	58	0	0	2	0	13	0	0
4.1.6	Maneuver to Burn Attitude	Tug				13	0	0	0	5	0	13	5	0
4.1.7	Report Status to Tug Opns Ctr	G/T	Gnd			13	5	0	0	1	0	13	6	0
4.1.8	Perform POI Burn (Main Engine)	Tug				13	6	0	0	17	0	13	23	0
4.1.9	Orbiter Monitor Dept/Perf On-Orb Opns	Orbiter				13	6	0	0	0	0	13	6	0
4.1.10	Position and Velocity Readout	G/T				13	23	0	0	5	0	13	28	0
4.1.11	Report Status to Tug Opns Center	G/T				13	28	0	0	1	0	13	29	0
4.1.12	Coast (Mission Dependent)	Tug				13	29	0	1	21	0	14	50	0
4.2.0	Transfer Orbit	Tug				14	50	0	0	0	0	14	50	0
4.2.1	Attitude Update	Tug				14	50	0	1	0	0	15	50	0
4.2.2	Position and Velocity Update	G/T				15	50	0	0	5	0	15	55	0
4.2.3	Compute TOI Burn Parameters	Tug				15	55	0	0	1	0	15	56	0
4.2.4	Maneuver to Reqd Attitude for TOI Burn	Tug				15	56	0	0	5	0	15	1	0
4.2.5	Verify Subsystems Ready for Burn	Tug				16	1	0	0	2	0	16	3	0
4.2.6	Report Status to Tug Opns Center	G/T				16	3	0	0	2	0	16	5	0
4.2.7	Perform TOI Burn (Main Engine)	Tug				16	5	0	0	14	0	16	19	0
4.2.8	Coast, Position and Velocity Update	G/T				16	19	0	1	0	0	17	19	0
4.2.9	Determine Params for Midcourse Correctn	Tug				17	19	0	0	1	0	17	20	0
4.2.10	Maneuver to Reqd Attit for Corr Burn	Tug				17	20	0	0	5	0	17	25	0
4.2.11	Report Status to Tug Opns Center	G/T				17	25	0	0	2	0	17	27	0
4.2.12	Perform MCC Burn - Pump Idle Mode	Tug				17	27	0	0	2	0	17	29	0
4.2.13	Position and Velocity Readout	G/T				17	29	0	0	5	0	17	34	0
4.2.14	Report Status to Tug Opns Center	G/T				17	34	0	0	2	0	17	36	0
4.2.15	Coast Operations	Tug				17	36	0	2	32	0	20	8	0
4.3.0	Payload (Geosynchronous) Orbit	Tug				20	8	0	0	0	0	20	9	0
4.4.0	Payload Deployment	Tug				22	59	0	0	0	0	22	59	0
4.5.0	Payload Target Phasing Orbit	G/T				24	19	16	0	0	0	24	19	16

Note 1: (X) = Orbiter Backup to Ground Function

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025) (Contd)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Min	Sec	Event Duration Hr	Min	Sec	Elapsed Time Hr	Min	Sec
4.6.0	Rendezvous Orbit Insertion	G/T				94	20	0	0	0	0	94	20	0
4.6.3	Compute Rendez. Circularization Parmas	Tug				95	25	0	0	1	0	95	25	0
4.7	Rendezvous With Target Spacecraft	Tug				96	20	0	0	0	0	96	20	0
4.8	Payload Docking	G/T/PL				98	35	0	0	0	0	98	35	0
5.0	Return Rendezvous	Tug				102	54	0	0	0	0	78	54	0
5.1.0	Return Transfer Orbit	Tug				102	54	0	0	0	0	105	54	0
5.2.0	Return Phasing Orbit	Tug				108	8	0	0	0	0	108	8	0
5.3.0	Orbiter - Rendezvous Orbit	Tug				131	1	0	0	0	0	131	1	0
5.3.1	Attitude Update	Tug				131	1	0	1	0	0	132	1	0
5.3.2	Position and Velocity Update	G/T				132	1	0	0	5	0	132	6	0
5.3.3	Compute Rendezvous Orbit Burn Params	Tug				132	6	0	0	1	0	132	7	0
5.3.4	Maneuver to Reqd Attit for ROI Burn	Tug				132	7	0	0	5	0	132	12	0
5.3.5	Verify Tug S ubsys Ready for TOI Burn	Tug				132	12	0	0	2	0	132	14	0
5.3.6	Report Status to Tug Opns Center	G/T				132	14	0	0	2	0	132	16	0
5.3.7	Perform ROI Burn (Main Eng.) 160 N.Mi.	Tug				132	16	0	0	3	0	132	19	0
5.3.8	Position and Velocity Readout	O/T	P			132	20	0	0	5	0	132	25	0
5.3.9	Stationkeep, Radar Lock-on	G/O/T	Gnd (MS)	(403)	2 sec	132	25	0	0	10	0	132	35	0
5.3.10	Report Status to Mission Control	G/T	MS			132	35	0	0	2	0	132	37	0
5.3.11	Coast Operations	Tug				132	37	0	0	0	0	132	37	0
5.4.0	Safe Tug	G/T	Gnd (MS)	(407)		132	30	0	0	0	0	132	30	0
5.4.1	Disarm Main Propulsion System	G/T	Gnd (MS)	(402)	30 sec	132	30	0	0	0	30	132	30	30
5.4.2	Close Main Propellant Isol. Valves	Tug				132	30	0	0	0	0	132	30	0
5.4.3	Open Main Engine Valve - Dissipate Prop.	Tug				132	30	0	0	2	0	132	32	0
5.4.4	Close Main Engine Valves	Tug				132	32	0	0	0	0	132	32	0
5.4.5	Retract Nozzle	Tug				132	32	0	0	1	0	132	33	0
5.5.0	Rendezvous with Tug (Orbiter Ops)	Orbiter				132	25	0	0	0	0	132	25	0
5.5.1	Arm Deployment Adapter	Orbiter	P	301	30 sec	132	25	0	0	1	0	132	26	0
5.5.2	Rotate Deploymt Adaptor to Docking Attit	Orbiter	P	303	2 min	132	26	0	0	5	0	132	31	0
5.5.3	Release Manipulator Arm Latches	Orbiter	P			132	31	0	0	1	0	132	32	0
5.5.4	Extend Manipulator	Orbiter	P			132	32	0	0	3	0	132	35	0
5.5.5.	Estab. Comm Between Tug and Orbiter	O/T	MS			132	38	0	0	2	0	132	40	0
5.5.6	Verify Orbiter to Tug RF Command	O/T	MS			132	39	0	0	1	0	132	40	0
5.5.7	Verify Orbiter has Tugs Attit Control	O/T	MS	403	2 sec	132	39	0	0	2	0	132	41	0
5.5.8	Maneuver to Rendezvous Attitude	O/T	C, MS	403	2 sec	132	40	0	0	5	0	132	45	0
5.5.9	Stationkeep	Orbiter	C			132	45	0	0	0	0	132	45	0
5.5.10	Verify Deployment Adaptor Ready to Recv Tug	Orbiter	P			132	45	0	0	2	0	132	47	0
5.5.11	Determine Range and Range Rate	Orbiter	C			132	47	0	0	5	0	132	52	0
5.5.12	Determine Rendezvous Intercept Maneuver	Orbiter	C			132	52	0	0	5	0	132	57	0
5.5.13	Compute Burn Parameters	Orbiter	C			132	57	0	0	1	0	132	58	0
5.5.14	Maneuver Orbiter for Proper Burn	Orbiter	C			132	58	0	0	5	0	133	3	0
5.5.15	Verify Orbiter Readiness for Burn	Orbiter	C			133	3	0	0	1	0	133	4	0
5.5.16	Perform Burn (OMS)	Orbiter	C			133	4	0	0	3	0	133	7	0
5.5.17	Coast, Hohmann Transfer	Orbiter	C			133	7	0	0	40	0	133	47	0
5.5.18	Verify Safety Status of Tug	O/T	MS	406	1 min	133	42	0	0	3	0	133	45	0
5.5.19	Orient Orbiter for Final Maneuvers	Orbiter	C			133	45	0	0	3	0	133	48	0

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025) (Contd)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Min	Sec	Event Duration Hr	Min	Sec	Elapsed Time Hr	Min	Sec
5.5.20	Perform Final Burn Maneuvers (APS)	Orbiter	C			133	48	0	0	5	0	133	53	0
5.5.21	Stationkeep (Crew Task Time)	O/T	MS	403		133	53	0	2	37	0	136	30	0
									(0	10	0)			
5.6.0	Tug-Orbiter Docking	O/T				136	30	0	0	0	0	136	30	0
5.6.1	Command Tug Orient to Pref Dkng Attitude	O/T	P,MS	403		136	30	0	0	5	0	136	35	0
5.6.2	Vis Insp Tug for Dkng Readiness	Orbiter	C,P			136	35	0	0	5	0	136	40	0
5.6.3	Maneuver Orb to Docking Posn, Stationkeep	O/T	C,P			136	40	0	0	5	0	136	45	0
5.6.4	Inhibit Tug APS system	O/T	MS	401	30 sec	136	41	0	0	0	0	136	41	0
5.6.5	Attach Manipulator To Tug	Orbiter	P			136	41	0	0	2	0	136	43	0
5.6.6	Verify Manipulator Attachment Secure	Orbiter	P			136	43	0	0	1	0	136	44	0
5.6.7	Verify Tug Subsys Safe for Retraction	O/T	MS	406	1 min	136	44	30	0	1	30	136	46	0
5.6.8	Retract Tug Onto Adaptor	Orbiter	P			136	46	0	0	5	0	136	51	0
5.6.9	Latch and Secure Tug to Base Ring	O/T	P	305	30 sec	136	51	0	0	3	0	136	54	0
5.6.10	Connect Electrical Umbilicals	O/T	P	304	30 sec	136	54	0	0	3	0	136	57	0
5.6.11	Verify Monitoring of Caut. & Warning	Orbiter	P	101	Cont.	137	7	0	0	0	30	137	7	30
5.6.12	Turn Off RF Link	O/T	P	204	1 sec	137	7	30	0	0	30	137	8	0
5.6.13	Orbiter Power to Tug, Fuel Cells Off	O/T	P	501, 203	3 sec	136	57	0	0	1	0	136	58	0
5.6.14	Release, Stow, Deactivate Manipulator	Orbiter	P			136	58	0	0	3	0	137	1	0
5.6.15	Rotate Tug into Cargo Bay	O/T	P	303	2 min	137	1	0	0	5	0	137	6	0
5.6.16	Latch Tug Forward Position to Orbiter	Orbiter	P			137	6	0	0	1	0	137	7	0
5.6.17	Connect Fluid Umbilicals	O/T	P	302	30 sec	137	7	0	0	1	0	137	8	0
5.7.0	Phase in Orbit	O/T				137	8	0	25	9	0	162	17	0
6.0.0	Descent Operations	Orbiter				162	18	0	0	0	0	162	17	0
6.1.0	Configure Cargo Bay for Reentry	Orbiter				162	17	0	0	5	0	162	22	0
6.2.0	Configure Tug Subsys for Reentry	O/T	MS	206	1 min	162	22	0	0	2	0	162	24	0
6.3.0	Secure Loose Articles in Cabin	Orbiter				162	17	0	0	10	0	162	27	0
6.4.0	Position and Velocity Update	G/O				162	27	0	0	5	0	162	32	0
6.5.0	Re-Orient Orbiter for Descent Firing	Orbiter				162	32	0	0	5	0	162	37	0
6.6.0	Close Cargo Bay Doors	Orbiter				162	32	0	0	2	0	162	34	0
6.7.0	Compute De-Orbit Burn Parameters	Orbiter				162	37	0	0	1	0	162	38	0
6.8.0	Maneuver to Reqd Attit for De-Orb Burn	Orbiter				162	38	0	0	5	0	162	43	0
6.9.0	Verify Subsystems Ready for De-Orbit	Orbiter				162	43	0	0	2	0	162	45	0
6.10.0	Report Status to Mission Control	G/O				162	45	0	0	2	0	162	47	0
6.11.0	Perform De-Orbit Burn	Orbiter				162	47	0	0	2	16	162	49	16
6.11.1	Dump Tug Propellants and	O/T	MS	207	1 min	162	47	0	0	2	0	162	49	0
6.11.2	Purge Tug Tanks	Tug				162	49	0	0	4	0	162	53	0
6.12.0	Coast for Atmospheric Entry	Orbiter				162	49	30	0	5	30	162	55	0
6.13.0	Re-Orient for Atmospheric Entry	Orbiter				162	55	0	0	5	0	163	0	0
6.14.0	Begin Insulation Purge	Tug				162	55	0	0	0	0	162	55	0
6.15.0	Re-Enter Atmosphere	Orbiter				163	0	0	0	4	0	163	4	0
6.16.0	Aerodynamic Coast	Orbiter				163	4	0	0	9	30	163	13	30
6.16.1	Lock LH_2 Vent, 90K Ft	Tug				163	4	0	0	0	0	163	4	0
6.16.2	Estab Airspeed and Alt Cntrl Parameters	Orbiter				163	4	0	0	4	0	163	8	0
6.16.3	Re-establish Radio Contacts	Orbiter				163	8	0	0	5	0	163	13	0
6.16.4	Verify Radar Coverage	Orbiter				163	8	0	0	5	0	163	13	0
6.16.5	Unlock LH_2 Vent, 20K Ft	Tug				163	9	0	0	0	0	163	9	0

Table 4.6-15. Tug Crew Effectivity Analysis (I/T 74-025) (Contd)

Event No.	Event Name	Vehicle	Crew	Orbiter S/W	Orbiter S/W Time	Event Start Time Hr	Event Start Time Min	Event Start Time Sec	Event Duration Hr	Event Duration Min	Event Duration Sec	Elapsed Time Hr	Elapsed Time Min	Elapsed Time Sec
6.16.6	Prepare Orbiter Subsystems for Landing	Orbiter				163	10	0	0	5	0	163	15	0
6.16.7	Configure Cabin for Landing	Orbiter				163	12	30	0	1	0	163	13	0
7.0.0	Land Orbiter	Orbiter				163	18	0	0	24	0	163	42	0
7.1.0	Estab Communications with Landing Zone	G/O				163	18	0	0	3	0	162	21	0
7.2.0	Gear Down	Orbiter				163	21	0	0	0	30	163	21	30
7.3.0	Begin Terminal Area Energy Management	Orbiter				163	21	30	0	20	30	163	42	0
7.3.1	Monitor Airspeed, Altitude	Orbiter				163	21	30	0	20	30	163	42	0
7.3.2	Final Approach	Orbiter				163	38	0	0	4	0	163	42	0
7.4.0	Touchdown	Orbiter				163	42	0	0	0	0	163	42	0
7.5.0	Rollout	Orbiter				163	42	0	0	0	45	163	42	45

Figure 4.6-21. Tug/Orbiter Ascent Crew Stations

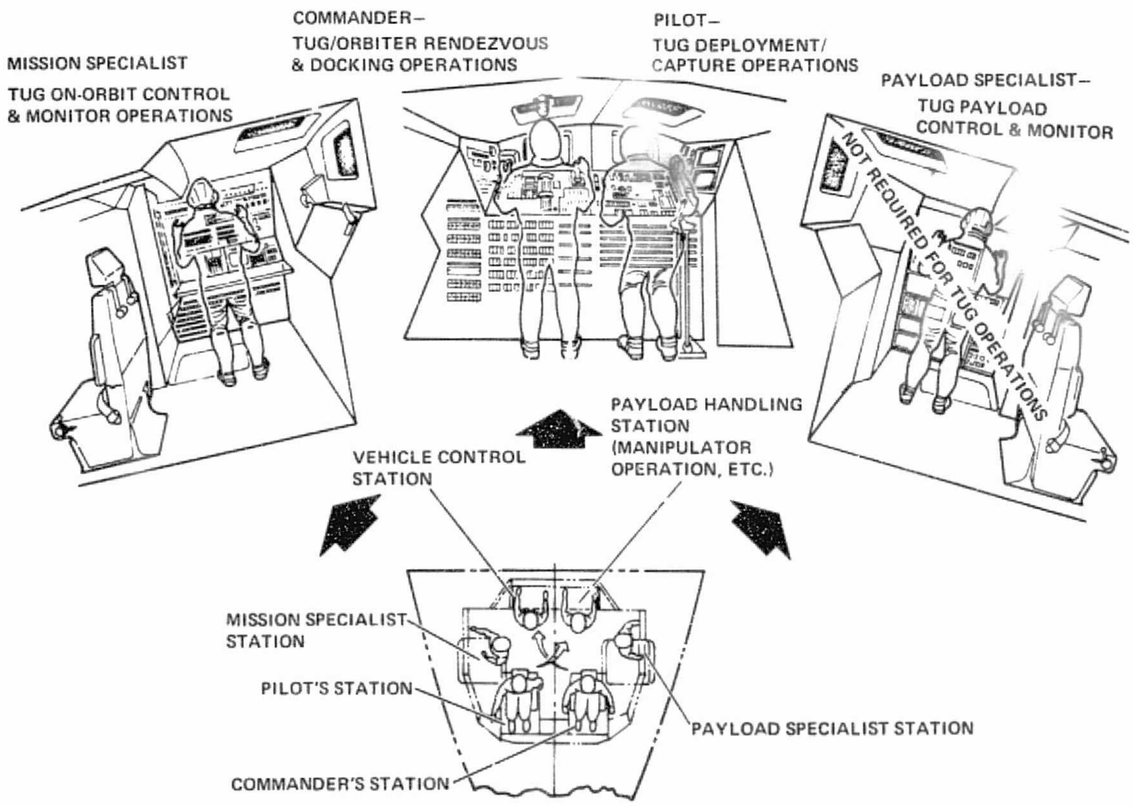


Figure 4.6-22. Tug On-Orbit Crew Stations

and Tug, plus Tug initialization and configuration validation. These commands would be initiated through a Tug control panel located at the MSS work station. The control and monitor functions associated with the various control panels are shown in Figures 4.6-23 and 4.6-24.

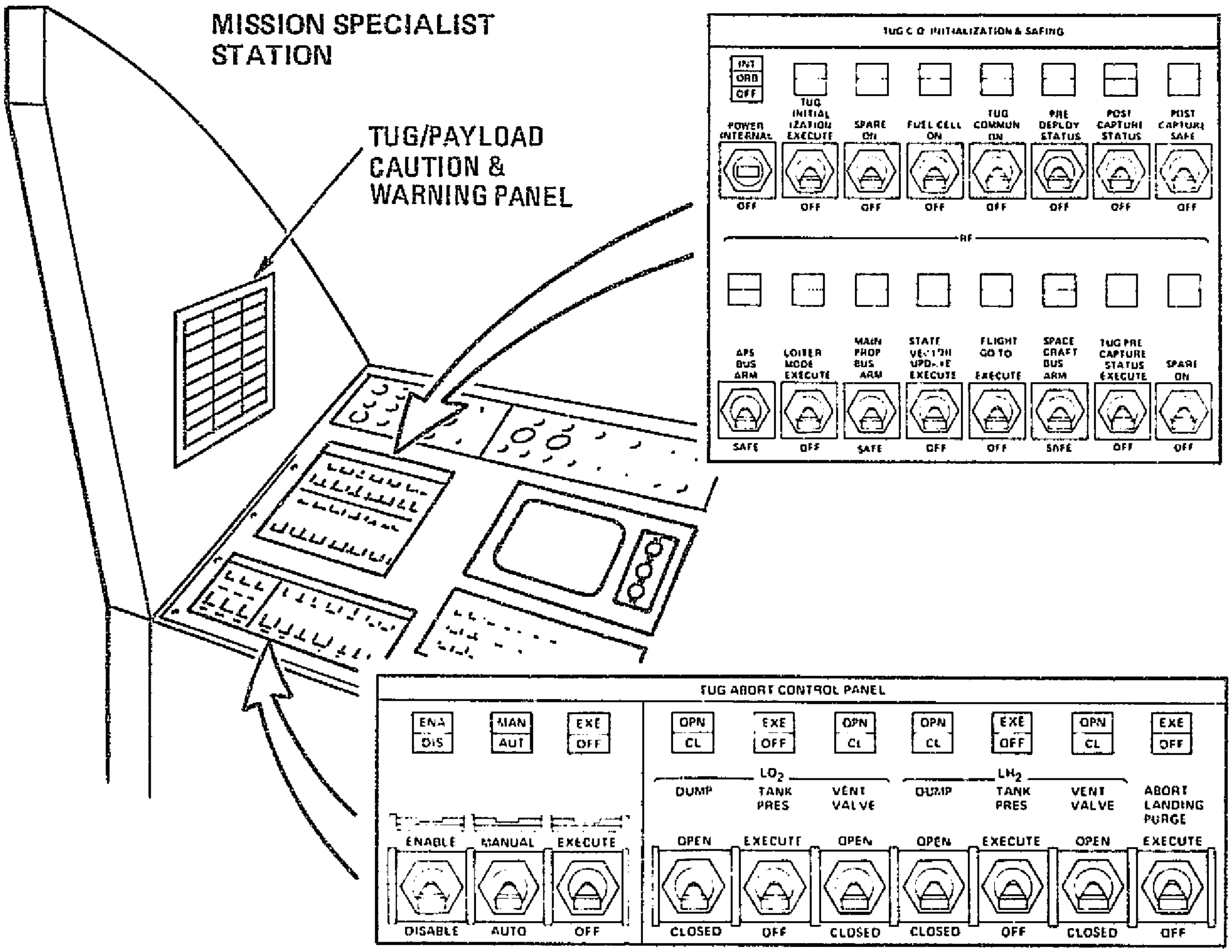


Figure 4.6-23. Tug Man-Machine Interface at MSS

The philosophy developed for automated support of Tug control and monitor activities is:

a. Large numbers of control panel switches and monitor lamps (and the panel space and interface electronics) can be avoided by employing the payload support data processor and Tug-unique software to transmit, monitor, and verify commands to the Tug and deployment adapter.

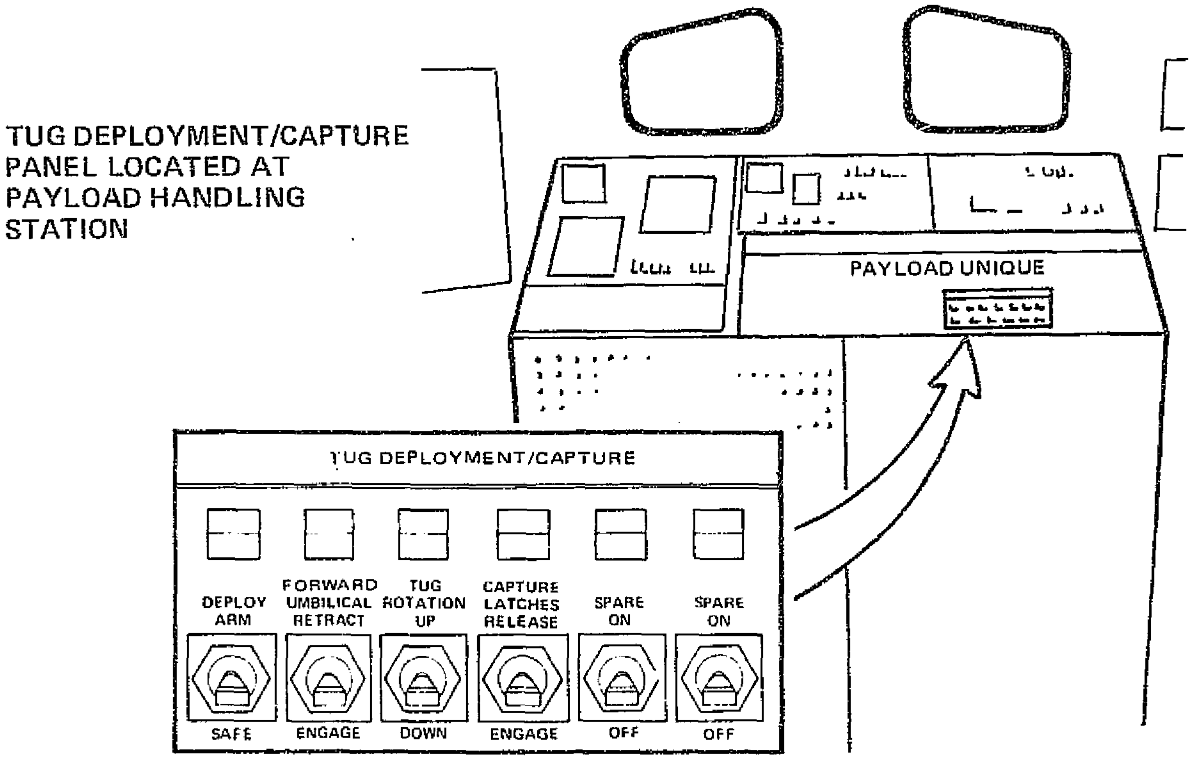


Figure 4.6-24. Tug Man-Machine Interface at PHS

b. Automated control and monitor sequences should be initiated in one of three ways:

1. Normal routine command sequences (such as release deployment latches), which occur as procedures during each mission, and safety-critical command and monitor sequences (abort) should be initiated by a manual switch located on the appropriate control panel. In operation, the switch would be connected to the discrete input module of the payload MDM unit, where the change of state would be recognized by a Tug-unique watchdog software program. This in turn would cause execution of the appropriate software application program.

2. The Orbiter MCDS CRT and keyboard would be used primarily for nonroutine operations such as fault isolating or to backup the panel switches. These functions would be in addition to their normal role of supplying operational status information to the mission specialist.

3. The crew would be provided rapid access (within 5 seconds via CRT and keyboard) to selected telemetry data, which summarizes Tug and deployment adapter downlink data indicating system and subsystem status and any anomalous conditions.

In summary, the intent of the preceding philosophy is to provide the Orbiter crew with sufficient information and capability to actively control Tug operations (initiate,

monitor, analyze, investigate) but not burden them with complex/routine manual or mental tasks that can be performed by an automated support system in a reliable, repeatable, controlled manner.

4.3.6 AVIONICS NONFUNCTIONAL INTERFACE EVALUATION. Tug interfaces identified as nonfunctional interfaces represent those interfaces that may affect the Tug/Orbiter operations but are not associated with Tug/Orbiter control and monitoring operations. Three nonfunctional interfaces were evaluated as part of the interface study tasks and are discussed in the following text. The nonfunctional interfaces evaluated involved Tug/Orbiter power return and grounding philosophy and EMC; payload RTG radiation effects on Tug avionics; and evaluation of Tug/Orbiter rendezvous and docking problems resulting from static charge buildup on either vehicle (see Figure 4.6-25).

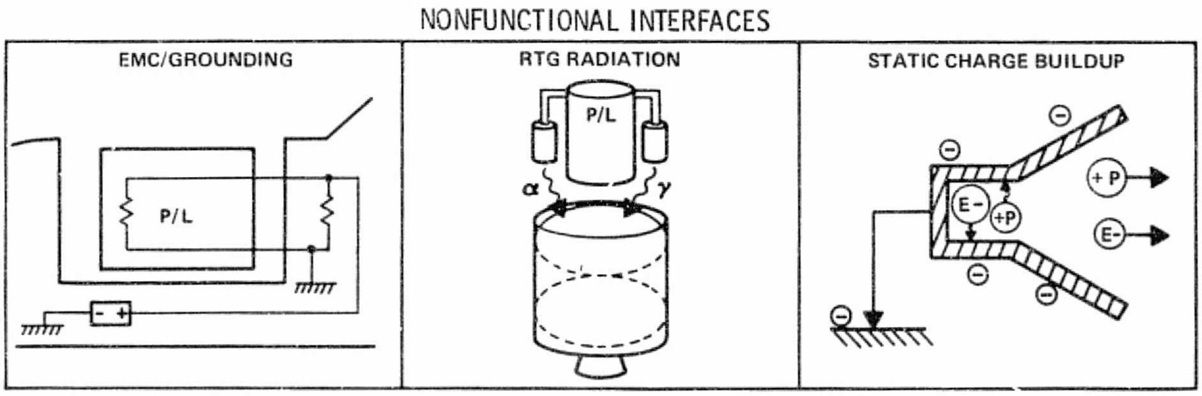


Figure 4.6-25. Tug Nonfunctional Interfaces

Tug/Orbiter Single Point Versus Multiple Point Ground. An analysis of the Tug/Orbiter grounding concepts was performed to evaluate the acceptability of Orbiter multipoint (MPG) ground philosophy with respect to the Tug preferred single point ground (SPG) concept. This analysis assumed an Orbiter configuration in which transient Orbiter load currents at locations forward of the cargo bay, between Stations 576 and 1307, and aft of Station 1307, were 530A, 100A and 300A respectively. Superimposed on the Orbiter power requirements were Tug/spacecraft and deployment adapter loads of 84A and 28A respectively. Using an Orbiter dc electrical model (data from NAR report "Space Shuttle Payload Grounding Study") wherein: 1) the forward cabin return path impedance (R_F) was 2.5 mΩ, 2) the cargo bay (structure) impedance (R_M was 25 $\mu\Omega$; and 3) the aft Orbiter return path (R_A) was 2.5 mΩ; a maximum noise transient of approximately 1.5 volts was found to be imposed on the Tug/spacecraft and deployment adapter ground as a result of Orbiter load switching (for the MPG versus SPG). This model is shown in Figure 4.6-26.

This voltage is within the specified tolerance of power supplied to payloads by the Orbiter system. Thus, it is concluded that payloads designed to operate using Orbiter

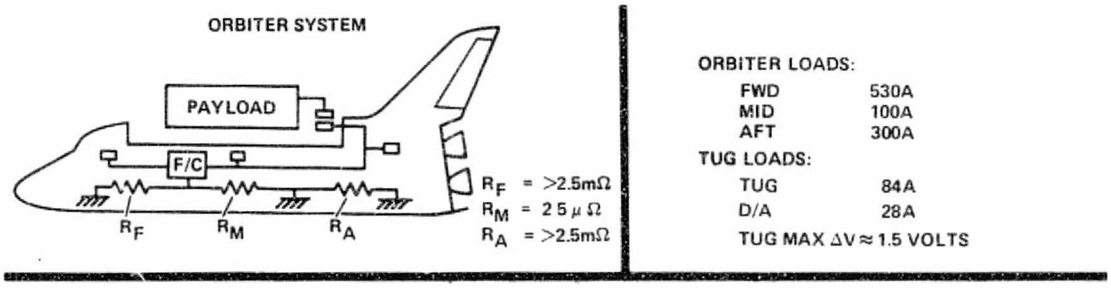


Figure 4.6-26. Orbiter/Tug Multiple-Point Ground dc Electrical Model

supplied +28 Vdc power as specified in JSC 07700 (Table 4.6.6-1) can operate in principal using the Orbiter MPG philosophy.

Table 4.6-16. Shuttle Payload Power

28 Vdc Nominal	
Steady-state limits:	23-40.5V intermittent
	24-30.5V continuous
Ripple voltage:	4V peak-to-peak
Payload power:	1,000 W operations 3,000 W coast

The primary difference between the two philosophies for Tug/Orbiter operation is that use of a MPG system would force both Tug/spacecraft and aft Orbiter load currents to return to the Orbiter power reference through the same path (Orbiter structure). This point is illustrated in Figure 4.6-27 where it is shown that Tug load currents are returned directly to the Orbiter fuel cell ground plane in the SPG system; and for the MPG system, the Tug power return is connected to the Orbiter ground at or aft of the cargo bay interface at Orbiter station 1307. This makes Tug/spacecraft avionics susceptible to transient noise due to switching (on or off) of Orbiter loads. Other differences include: 1) twisted shielded pair cable could be easily used with the SPG system to reduce coupling between Tug/spacecraft and Orbiter systems, 2) the well-defined return path provided by SPG systems will ease identification and correction of noise problems involving ground loops.

A comparison of the two philosophies indicates that higher Orbiter DDT&E cost and weight penalties will result from a single point ground system due primarily to the increased cabling required to route payload +28 Vdc return to a common Orbiter ground point near the Orbiter fuel cell systems. However, it should be noted that several advantages associated with the SPG philosophy may decrease payload and Orbiter costs associated with payload/Orbiter integration, testing, problem isolation, and requirements redefinition, thus offsetting the initial Orbiter DDT&E cost difference.

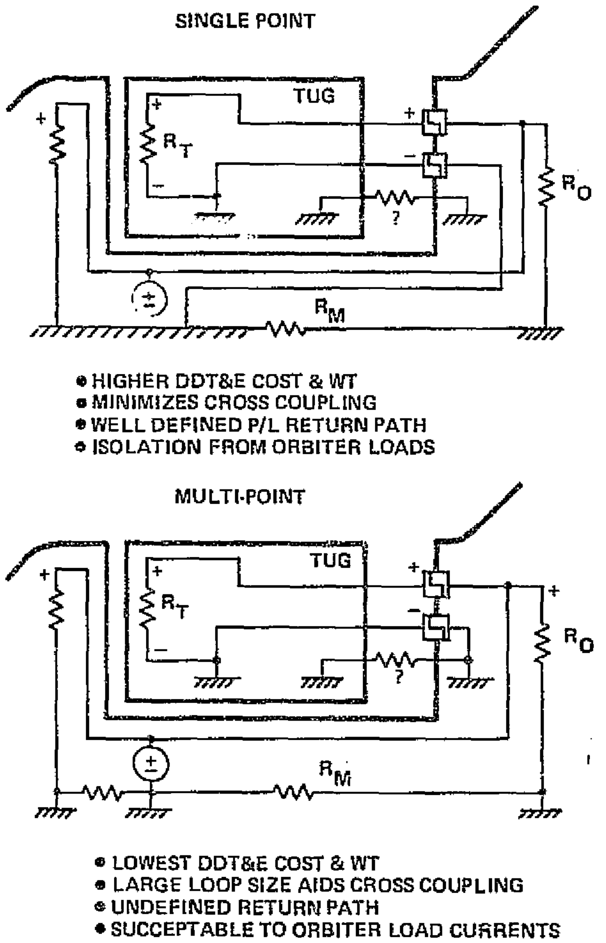


Figure 4.6-27. SPG vs MPG Comparison

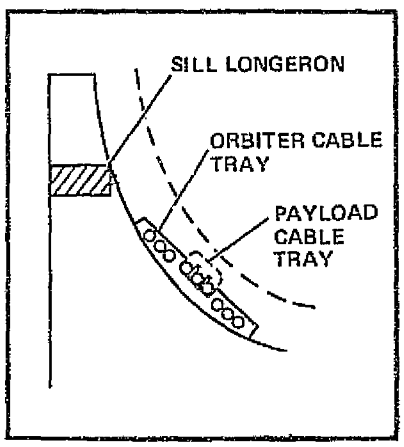


Figure 4.6-28. Orbiter/Payload Cable Tray Locations

The results of the single point ground (SPG) versus multipoint ground (MPG) investigations indicate that the MPG system is acceptable for Tug/Orbiter operations; however, the preferred method is to employ SPG philosophy. Two areas of concern identified as a result of the investigation are: 1) low-level analog and digital interface signals between the Tug/spacecraft and Orbiter (such as C&W signals) are expected to exhibit transient noise, which may interfere with interface operations; and 2) the Tug support fittings that interface the Tug to Orbiter should not be used as a ground return path, because these fittings attach to the relatively nonconductive Tug graphite-epoxy structure and not directly to the Tug avionic ground plane.

The payload wire trays provided by the Orbiter were investigated and found to be acceptable in that provisions were made for separation of Orbiter signal cables from payload signal cables (B/A metal Orbiter wire tray cover), and partitions within the payload portion of the wire tray will allow separation of payload signals by type (RF, analog, digital). See Figure 4.6-28.

An investigation of an Orbiter lightning strike (during launch) was also conducted to determine the effect on the payload ground due to large lightning induced current flowing in the Orbiter cargo bay structure (Figure 4.6-29). It was found that lightning should have minimal effect (0.5 volt transient) on payloads; however, it should be noted that the investigation did not consider the effect of the lightning-induced electromagnetic fields on the Tug or spacecraft systems. Current launch vehicle program past experience would suggest using twisted shielded

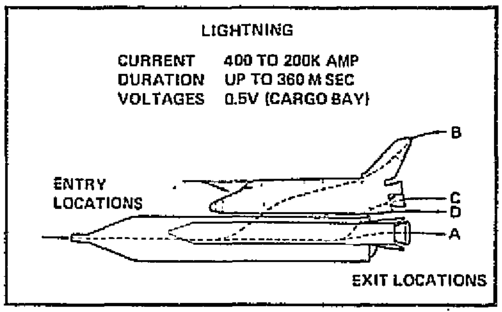


Figure 4.6-29. Orbiter/Tug Lightning Model Characteristics

cable and isolation or current-limiting devices on interface signals and their respective circuits.

It is recommended for Tug/Orbiter MPG operations that the Orbiter implement payload grounding provisions at Orbiter locations Stations 576, 695, and 1307 for both payload return cables and payload cable connector backshells that interface with panels at these locations. In addition it is recommended that the payload ground returns on the Orbiter side of these panels be connected directly to the Orbiter structure rather than be part of an aft Orbiter ground bus tree through which large Orbiter currents flow. This action will allow Tug and Orbiter return current to be routed to the cargo bay structure in a parallel manner thus minimizing the effective connection impedance-induced voltages. It is also suggested that the Orbiter sill longerons be investigated as possible ground connection points for Orbiter payloads since they run the length of the cargo bay on both sides of the Orbiter and provide a relatively unobstructed path for payload return current.

Tug Susceptibility to Payload RTG Radiation. Space Tug missions subject the Tug avionics to a variety of natural and man-made radiation, which may degrade the Tug performance or its components. Natural radiation sources to be encountered will depend on the specific mission characteristics but will include: Van Allen belts and the South Atlantic anomaly (protons and electrons), cosmic radiation (high-energy charged particles from outside the solar system), plus the solar wind and associated solar flares (high-energy protons and charged particles). Artificial or man-made sources of radiation include the spacecraft radioisotope thermoelectric generators (RTGs) used to provide spacecraft electrical power. The effect of one of these sources of radiation was investigated as part of the Interface study special emphasis work.

A preliminary investigation was conducted to determine if spacecraft RTGs would cause damage to Tug avionic components. The nuclear radiation flux environment model used to determine the effect of payload RTGs on Tug avionics systems is shown in Figure 4.6-30 along with typical nuclear radiation environment data from natural space radiation sources. A spacecraft of the MJS-77 type with three MHW model RTG units mounted as shown in the diagram was assumed for this analysis. This payload (and associated RTG units) was chosen for this analysis because it closely resembles NASA planetary payloads (PL-11A through PL-13A) proposed for Orbiter launch during the 1981 through 1986 time period.

In the configuration shown, RTG units located 18 in. (0.5 m) above the Tug avionics produce a nuclear radiation environment consisting of alpha particles (neutrons) and

RADIATION SOURCES	PARTICLES	FLUX/ cm^2/SEC	ENERGY (MEV)
• PAYLOAD RTGs	ALPHA GAMMA	2,900 170×10^{-3} RAD/HR	
• VAN ALLEN BELTS	PROTONS PROTONS ELECTRONS ELECTRONS ELECTRONS	10^3 6×10^4 10^8 $10^4 - 10^5$ 10^5	>5 30 - 100 >40 >1.6 >7.0
• SOUTH ATLANTIC ANOMALY	PROTONS ELECTRONS	10^3 10^7	>40 >0.5
• COSMIC RADIATION	PROTONS (ALPHA, ETC)	1.5 - 4	>1,000
• SOLAR FLARES	PROTONS PROTONS PROTONS	10^{12} 10^6 10^3	>10 KEV 10 - 500 >1,000

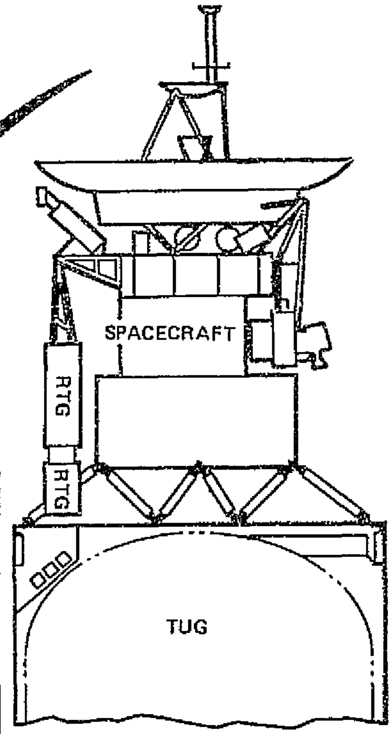


Figure 4.6-30. Tug Nuclear Radiation Environment

gamma rays at flux rates of 2900 neutrons per cm per second and 170 milli-rad per hour, respectively (Ref. JPL IOM No. 365-B-200-74). The Tug radiation levels indicated above are based on the following assumptions concerning RTG operating characteristics (referenced in JPL IOM-353:72-27):

1. 2400 watts (thermal) per RTG.
2. 10000 neutrons/sec-gm ^{238}Pu.
3. 1.18 subcritical multiplication factor.
4. 5-year old fuel.

Further assumptions concerning the Tug/spacecraft model used are given below. The 2.5 day exposure time is based on RTG unit installation on the spacecraft at T-2 days and Tug deployment of the spacecraft within 12 hours after Orbiter launch. This is conservative when compared with current launch vehicle practice of RTG installation at T-1 day and deployment within six hours of launch. The effect of radiation shielding due to avionics unit and individual component packaging was not taken into consideration and use of only current state-of-the-art nonhardened semiconductor components was assumed.

These assumptions result in RTG neutron and gamma radiation fluxes of 6.26×10^8 N/cm^2 and 10.20 Rad respectively per Tug mission. Thresholds of damage levels for bipolar and MOS devices are generally above 10^{11} N/cm^2 and 5×10^3 Rad (Table 4.6-17). Thus the results show that payload RTG units of the type and number used in the model would have no significant effect on Tug avionics. These results are based on analysis that indicates at least 159 average Tug missions carrying payloads typical of the test model would be required to degrade the Tug avionics to the damage threshold. A Tug design life of 20 missions, therefore, provides a factor of safety of approximately eight. The probability of RTG radiation damage is further reduced by the fact that only 14 payloads (10 percent) in the Tug mission model (NASA) will be equipped with RTG units. Thus even if all RTG carrying payloads were to be flown on one Tug vehicle, the Tug would not be degraded sufficiently to affect mission performance. Even greater factors of confidence can be obtained by spreading the RTG payload flights among the entire Tug inventory.

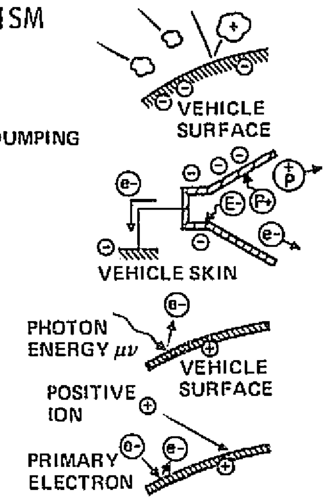
Table 4.6-17. General Radiation Damage Levels for Tug Avionics

Threshold of Damage		
Device	Gamma	Neutrons
Bipolar	10^4 Rad	10^{11} N/cm^2
MOS	$5 * 10^3$ Rad	10^{11} N/cm^2

It is important to note that these results should not be construed to imply that a Tug vehicle will experience no radiation damage during the operating life of the vehicle. This investigation did not take into account radiation from other sources (see Figure 4.6.6-6) and other Tug mission models. It is therefore recommended that a more thorough analysis be conducted for several mission types wherein all natural and artificial radiation sources are considered, and shielding and other secondary effects are taken into consideration. This evaluation should be accomplished per NASA TM X-64713 using the NASA radiation flux and dose rate determination programs.

Tug/Orbiter Static Charge Buildup. Several mechanisms can occur that may cause the Tug and/or Orbiter to become electrically charged during one or more inflight operations. A special emphasis task was conducted to determine if static charge accumulation on the Orbiter or Tug would create operational problems or damage (to either vehicle) during Tug rendezvous and docking operations. Tug/Orbiter/spacecraft problems which can result from this phenomenon include: 1) attraction of contaminating particles in the vicinity of the charged vehicle surfaces resulting in degradation of vehicle optical systems and thermal surfaces, and 2) electrostatic discharge of charged vehicle surfaces may generate sufficient EMI to interfere with avionics system operation or cause activation of pyrotechnic devices. Electrostatic discharge effects may also cause physical damage to vehicle dielectric surfaces such as the multilayer insulation (MLI), solar panels, and optics systems; a secondary effect of the physical damage mechanization is the release of additional contaminants.

The various charging mechanisms examined as part of this task include triboelectric charging, engine charging, and charging due to photoelectric and space plasma effects. The expected voltages due to these charging mechanisms as a function of the Tug/Orbiter/spacecraft mission phase, where each is applicable, is shown in Figure 4.6-31. These charging machanisms are briefly discussed below.



CHARGING MECHANISM	EXPECTED VOLTAGE	OPERATIONAL PHASE: ORBITER ASCENT	LOW EARTH	TUG ASCENT	P/L ORBITER
• TRIBO ELECTRIC • CLOUDS/DUST	20KV – 200KV	X			
• PROPELLANT DUMPING			X		
• ENGINE CHARGING • RL-10	0 – 20 KV			X	
• ACS			X		X
• PHOTO ELECTRIC	0 – 6.4V		X	X	X
• PLASMA EFFECTS	3V – 10KV		X	X	X

Figure 4.6-31. Tug/Orbiter Charging Mechanisms Contributing to Static Charge Accumulation

Triboelectric (or functional) charging results when vehicles fly through suspended particles (clouds, ice crystals, atmospheric or meteoric dust). Aircraft charging to 500 kilovolts and launch vehicle potentials of up to 200 kV (Titan III-C-20) have been observed due to this charging mechanism. The charging rate due to triboelectric charging is a function of the particle charge, particle density, particle/vehicle differential velocity and the contact surface area. The charge polarity acquired by the vehicle is a function of its surface dielectric constant with respect to the intercepted particle: the higher particle in the triboelectric series tends to acquire a positive charge.

Engine charging apparently results when the highly mobile electronics in the thermally ionized engine plasma migrate to the metallic engine walls (and then to the vehicle skin), and the heavier less mobile positive ions are expelled with the engine exhaust products. Charging potentials of up to 150 kV and 200 kV have been observed for aircraft and launch vehicles respectively. Charging characteristics associated with engine charging include: 1) engines always charge negatively, and 2) charging rate is a function of plasma temperature and altitude (affecting ion mobility). Engine charging decreases with altitude to less than 20 kV above 40 k feet. Little or no data is available concerning LO_2/LH_2 engine charging. It is tho ht, however, that due to the very high engine plasma temperature (6000R) and because almost complete ion

recombination occurs before combustion products are exhausted, little or no engine charging will result from Tug LO_2/LH_2 engine operation.

Photoelectric charging results when photons with energies of up to 50 kV cause photoemissions of electrons from illuminated vehicle surfaces. In the lower ionosphere, the electron density of the surrounding plasma are sufficiently high that electron collection predominates over photoelectric charging, and the vehicle acquires a small negative potential. In the upper regions of the ionosphere photoelectric, charging dominates on the sunlit side of the vehicle (0 - 6.4 V) and plasma charging predominates on the dark side (-2000 V) and during periods of eclipse (-11 kV). Ionosphere electron density as a function of altitude and ground track is shown in Figures 4.6-32 and 4.6-33 respectively.

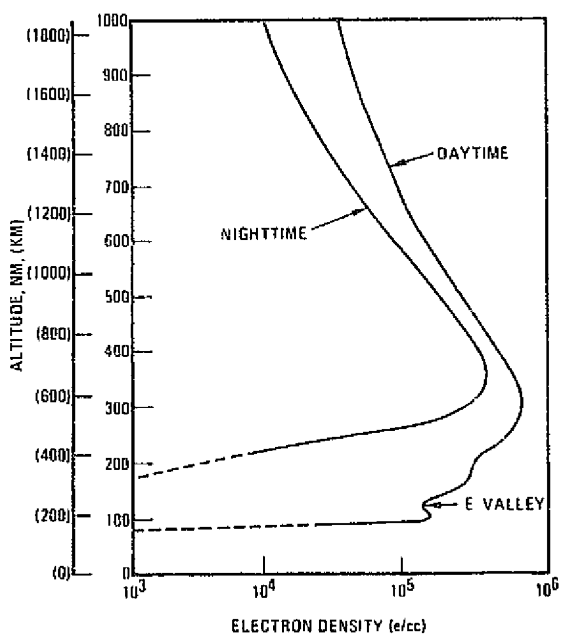


Figure 4.6-32. Vertical Electron Density Distribution (38 Deg Latitude, 75 Deg Longitude)

The results of this evaluation showing Tug/Orbiter voltage potentials expected during the various operational flight phases are plotted in Figure 4.6-34. Tug to Orbiter discharge problems are not expected during Orbiter ascent, deployment, and descent operations since the Tug and Orbiter are in constant contact during these operations and thus should develop no potential differences. This result does assume, however, that the Tug outer shell structure surface (graphite epoxy) is made conductive and is connected electrically to the Tug tank structure and also to the Orbiter structure through a Tug/Orbiter interface cable. Additionally, no problems are expected during Orbiter/Tug docking, since any charge acquired by either vehicle is expected to be quickly (within one millisecond) equalized by the highly ionized ionospheric plasma at the docking altitude (160 n.mi. (300 km)). Any problems due to electrostatic charging are expected to occur during Tug ascent or on-orbit operations where vehicle potentials (during eclipse) may be as great as 11 kV. Spike effects are depicted on the graph to indicate the effect of ACS engine burns.

The results indicate that no significant Tug/Orbiter docking problems due to discharge of static potential between the two vehicles is expected due to the high electron density at Orbiter docking altitudes and to the resulting short equalization times, which permit

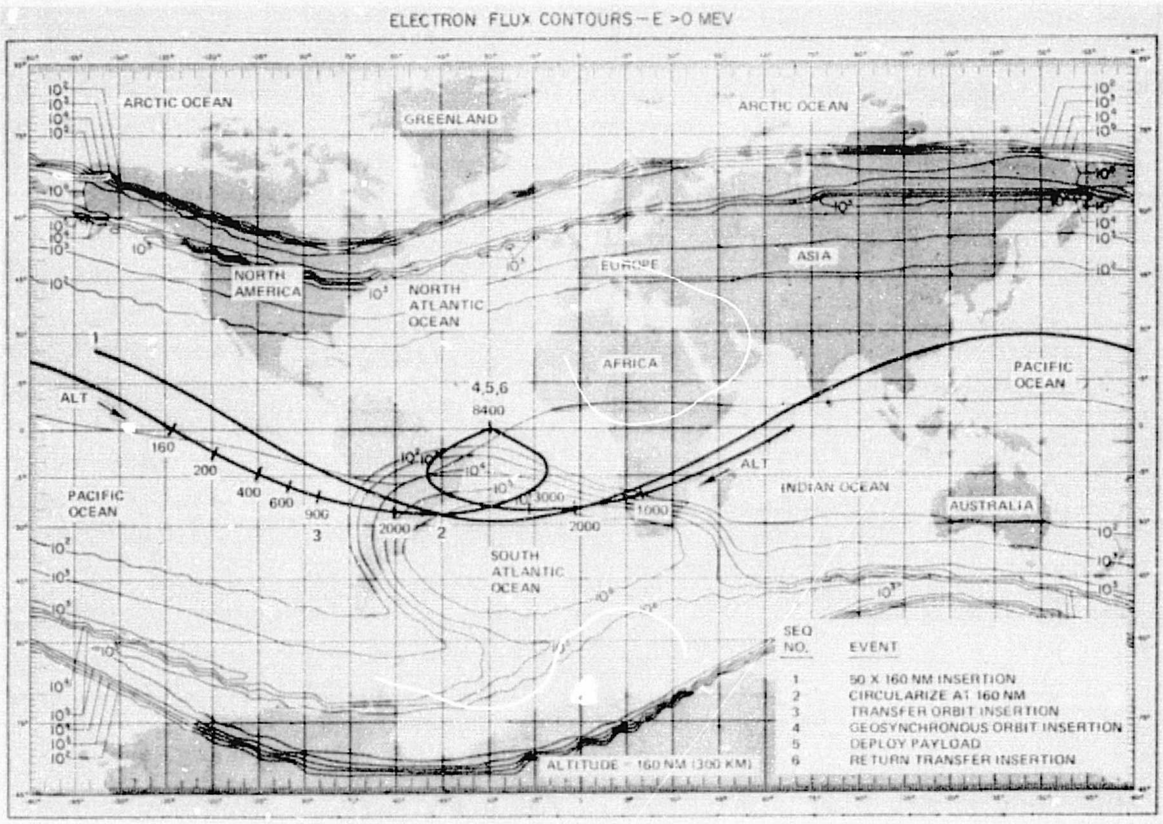


Figure 4.6-33. Typical Tug Mission Ground Track Superimposed on Map of Electron Flux Contours

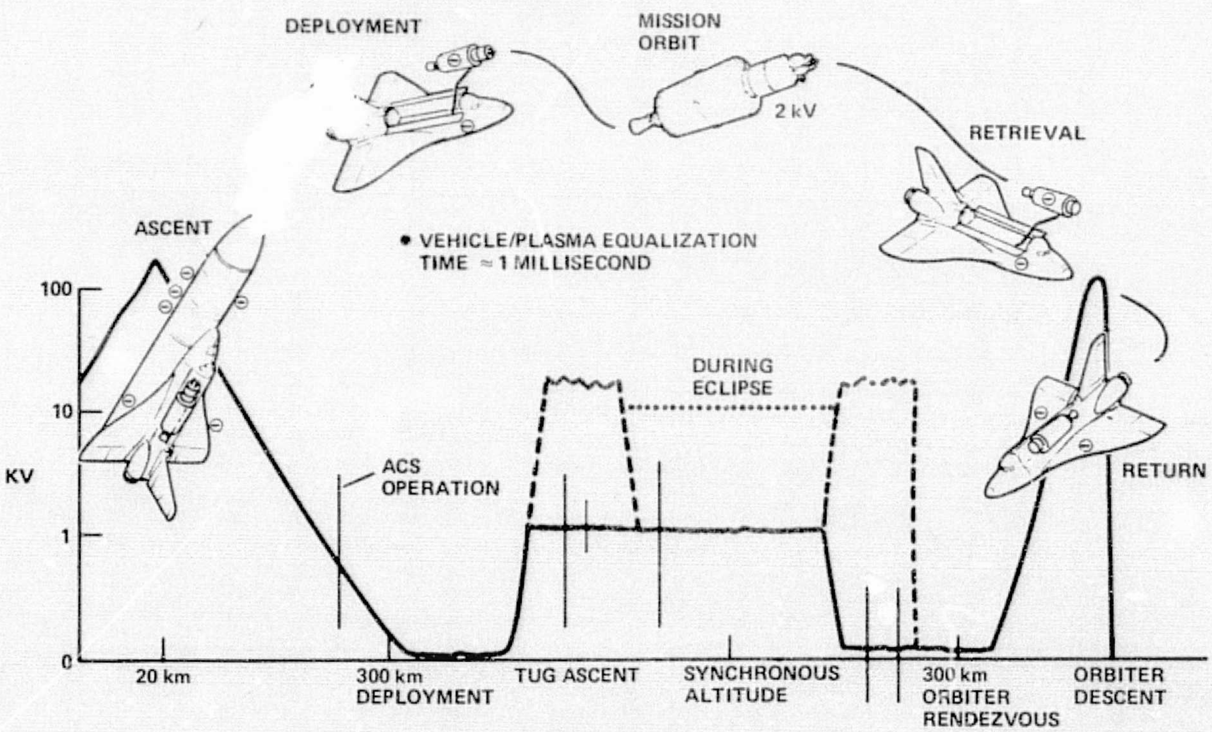


Figure 4.6-34. Tug/Orbiter Static Charge Per Operational Phase

both vehicles to be near the same potential prior to docking. Possible problems may occur at Tug/spacecraft mission orbits, however, and special attention may be required with respect to grounding of vehicle surfaces and Tug/spacecraft orientations (with respect to the sun) during Tug/spacecraft rendezvous and docking operations (see Figure 4.6-35).

To prevent the occurrence of electrostatic charge problems during Orbiter ascent/descent operations it is recommended that the Tug structure be well grounded to the Orbiter. It is also recommended that the Tug MLI insulation layers be grounded to the vehicle structure (Figure 4.6-36) and that methods be investigated to discharge the Tug graphite epoxy external surfaces by grounding the graphite layers or through conductive coating.

Because of the lack of charging data associated with LH_2 /LO_2 powered vehicles, it is further recommended that a Centaur vehicle be instrumented to collect engine charging, photoelectric and plasma charging data in the region from low earth altitude (160 n.mi. (300 km)) to synchronous altitude. A Titan-Centaur launch of a Helios satellite (TC-5) scheduled for 1976 will have excess performance capability that might be used for Tug development purposes.

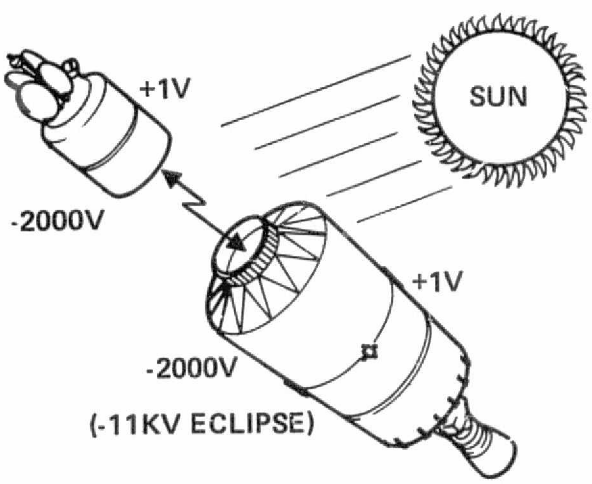


Figure 4.6-35. Expected Tug/ Spacecraft Vehicle Potentials at Synchronous Altitudes

Figure 4.6-36. MLI Bonding Technique

The above data reflects in part the results of previous space vehicle static charge studies and analysis. Documents referencing this task include:

C-6

A. Nanevicz, J.E., Pierce, E.T and Whitson, A.L. - Atmospheric Electricity and the Apollo Series, June 1972

B. "Thermal Shield Static Charge", Feb. 1975

C. D.A. McPherson - Spacecraft Charging at High Altitudes - the Scatha Satellite Program, Jan. 1975

D. Alan Rosen - Spacecraft Charging: Environment Induced Anomalies, Jan 1975

E. Adamo, R.C. and Nanevicz, J.E. - SRI Engineering Support for Skylab Contamination Experiment, Oct. 1972

F. Vance, E.F. and Nanevicz, J.E. - Rocket Motor Charging Experiments, June 1966

G. Nanevicz, J.E. and Chown, J.B. - SRI Experiments on AFCRL Nike-Cajun Rocket AD 6.842 and on Trailblazer II, Dec. 1967

H. Nanevicz, J.E. and Hilbers, G.R. - Titan Vehicle Electrostatic Environment, July 1973

I. Vance, E.F., Seely, L.B. and Nanevicz, J.E. - Effects of Vehicle Electrification on Apollo Electro-Explosive Devices, Dec. 1974

J. Nanevicz, J.E., Adamo, R.C. and Scharfman, W.E. - Satellite-Lifetime Monitoring, March 1974

K. Lightning and Static Electricity Conference 12-15 Dec. 1972

4.6.7 AVIONICS INTERFACE ISSUES AND RECOMMENDATIONS. The recommended Tug/spacecraft/Orbiter avionics interface configuration discussed in the preceding sections is the result of work performed to resolve several electrical interface issues so that operational complexity will be reduced. The major areas of concern and the resulting recommendations are discussed below and summarized in Figure 4.6-37.

a. Physical Interface in the Bay. These interfaces consist of aft bulkhead connectors for T-0 umbilical wires and for power, mid-bay connections for T-4 umbilicals and power, and forward bulkhead connectors for wiring to Orbiter payload support avionics. These interfaces are minimized by use of data links and using only hardwires for C&W monitors and power.

REDUCED TUG/ORBITER OPERATIONAL COMPLEXITY

Operational Interfaces	Operational Recommendations
Tug/Orbiter Electrical I/F - T-0, T-4 Umbilicals - Orbiter Cargo Bay Fwd & Aft - Orbiter Power I/F	Minimize Physical I/F Requirements - Multiplex majority of command & monitor - Hardwires only for inflight safety critical functions
Tug Support Equipment - Orbiter-Supplied Equipment - Tug Unique Equipment - MSS vs PSS	Optimize use of Orbiter support Equipment - Reduce Tug DDT&E costs - Simplify ground ops & turnaround - Standardized Orbiter equipment
Tug Support Software - GPC Software - Tug Unique Software	Use Orbiter S/W operating system - Provide Tug unique software per selected baseline - Reduce S/W complexity by using Tug capability - Minimize actual program count
Crew Effectivity - Commander - Pilot - Mission Specialist - Payload Specialist	Use 3-man crew - Commander: Orbiter maneuvering - Pilot: Manipulator station (Tug Deployment) - Mission Specialist: MSS (abort, status, control) - Payload Specialist: Not required for Tug

Figure 4.6-37. Tug/Orbiter Interface Recommendations

b. Tug Support Equipment. This equipment is located in the Orbiter crew compartment and falls into two categories: Orbiter-supplied gear and Tug-unique gear. By judicious use of the Orbiter's payload support hardware, Tug development costs for Tug-unique electronics is minimized. Also, maintenance and turnaround time between Tug and other Orbiter payload missions are reduced.

c. Tug Support Software. Software located within the Orbiter's rapid access and mass storage memories also falls into two categories: the Orbiter-supplied op-

erating system and Tug-unique software programs executed by the Orbiter's GPC. Software interface complexity can be reduced by using an executive/tenant approach wherein the Tug-unique software would operate within the Orbiter operating system and individual tenant programs would interface with a set of software tables. This will allow Tug supplied programs to be isolated from most of the real-time requirements associated with the Orbiter avionics system and the Tug/Orbiter hardware interface. Software complexity can also be reduced by using the Tug DMS capability in lieu of Orbiter and ground software whenever practical, and by limiting the numbers of Tug support programs to those frequently used.

d. Crew Effectivity. This involves the manner in which the crew members are used to perform tasks for P/L support such as status and C&W monitoring, activation, power control, arming/safing, deployment, and capture. Analysis has shown that a Payload Specialist is not required for Tug support, thus the TUG control and monitor panels and man-machine interface functions are shown to be located at the MSS station.

4.7 SAFETY AND RELIABILITY ANALYSES

The Tug interface design approaches were analyzed to assure that the recommended interface designs are both safe and reliable. The analyses were performed concurrent with the design effort, and the safety/reliability features were accordingly designed-in as an integral element of the interface study program.

4.7.1 SAFETY. The Tug interface safety requirements were defined early in the program (reference Sections 2.3 and 3.1.4) and were used as design stanards throughout the study. A study ground rule was imposed to assure that each safety requirement would be specifically addressed and a resolution to each requirement would be identified. The results of this implementation of Tug/Orbiter interface safety requirements are summarized in Table 4.7-1. The Tug/Spacecraft safety requirements are summarized in Table 4.7-2.

4.7.1.1 Exceptions to Safety Requirements. As indicated in the tables, the only Tug/Orbiter safety requirements to which exceptions are taken are: requirement 29, which requires horizontal drain capability for main propellants, and requirement 33, which requires positive seals at the fluid fill and drain disconnect. The rationale for the exceptions to these requirements are presented in the following paragraphs. The trade study data associated with the horizontal drain capability decision is presented in Figure 4.7-1.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
1. Tug safety data, controls, hardware, safety procedures, etc., that are necessary to prevent damage to and to insure the safety of the Orbiter shall be provided. The safety critical data, displays, and controls shall be capable of being verified functionally.	Tug safety controls/monitors for all safety critical functions are provided by Tug Data Bus Monitor Signals and by analog instrumentation (hardwired) for Caution and Warning functions. Backup control discretes for crew override of safety critical functions are also provided for in the interface design.
2. Materials, fluids, etc., shall not be released or ejected into the payload bay from the Tug. Venting, relief, and release of material from the Tug shall be through the Orbiter provided vent system. Control of the venting, etc., by the Orbiter for certain mission phases may be required.	All potentially hazardous fluids are vented external to the Orbiter via Orbiter provided vent systems. Emergency He dump capability, external to the Orbiter, is also provided in the interface design.
3. Redundant equipment having safety implications shall be located away from the primary source to which it provides safety protection or which prevent hazard propagation.	Redundant valves, controls etc., identified in the interface study are considered to be physically isolated to the maximum practical extent.
4. Where hazards can occur due to the presence or contact of mutally incompatible materials, fluids, electrical potential, etc., such as fuels and oxidizers, these materials, fluids, etc., shall be separated to the maximum possible extent.	All fuels and oxidizers are routed through separate disconnect panels. The fuel and oxidizer panels are located on opposite sides of the Tug adapter and are individually purged with He. The purge He for the fuel and oxidizer panels are individually vented external to the Orbiter.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
<u>Tug/Orbiter Requirements</u>	
5. Provisions shall be included for emergency manual release of Tug to Orbiter connections.	Tug to Orbiter connections are automatically released on Tug adapter rotation. Tug/adapter latches can be manually released via EVA.
6. Provisions shall be made for remote emergency jettisoning of Spacecraft deployment equipment and antennas as necessary to complete retrieval and stowage operations of the Tug.	Interface requirement: requires Spacecraft designers to provide this capability.
7. Tug shall provide at all time to the Orbiter such information as necessary concerning the status or condition of Tug and Spacecraft systems to ensure safety of Orbiter and crew. Provisions shall also be made for Orbiter override of safety critical Tug and Spacecraft functions during stowage aboard the Orbiter during Tug deployment and retrieval phases of operations.	Tug safety critical data that require urgent action on the part of the crew are contained in the Tug Caution and Warning panel. This data includes: LH_2 Tank Over- or Under pressure, LO_2 Tank Over- or Under pressure, and N_2H_4 tank pressures. Orbiter mounted arm/safe switches and command links provide override control of safety critical Tug and Spacecraft subsystems.
8. Provisions shall be included for control of all safety critical Tug functions, including attitude and translational position control by Orbiter crew during post-deployment and pre-retrieval operation for Orbiter/Tug separation distances to 20 n. mi.	Requires that avionics design be capable of performing these post-development and pre-retrieval operations via RF link.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
<u>Tug/Orbiter Requirements</u>	
9. Provisions shall be made to confirm that all safety critical Orbiter/Tug electrical connections, fluid lines, etc., interfaces are securely connected.	Verification of electrical connections can be verified by actuation of proximity switches on the disconnect panels and thru-plug continuity checks. Verification of fluid interconnects can be provided by a fluid detection monitor in the disconnect purge cavity.
10. Tug deploy/release/retract mechanisms shall not cause a hazard even after a failure has been experienced with that system(s).	Dual motors are used in each of the two deployment actuators. In the event of a jammed actuator, the design allows for disconnection of the failed actuator via the RMS or EVA and continued Tug deploy/restow operations.
11. Provisions must be made for verifying readiness of safety critical Tug systems before activation.	Readiness of safety critical Tug peripheral systems is verified by monitoring signals for the various safety critical functions to be performed (i.e., umbilical panel engaged, oxodizer panel engaged, etc.). Tug status check information is provided via Tug on-board checkout programs.
12. All mechanical, electrical and fluidic connections between the Tug and Spacecraft and Orbiter shall be fail safe.	All safety critical electrical connections are dual redundant. Fluid connections effectively utilize triple redundant seals and He purge to assure at least fail safe capability. Umbilical panel actuators are safed (power inhibited) while engaged.
13. Provisions shall be made for detecting the presence of spilled hazardous fluids or materials during handling or transfer.	It is intended that H_2, O_2 and N_2H_4 leak detectors be installed in the payload bay. This is an Orbiter interface requirement.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
14. Environmental control of the Tug, if required, shall be provided after propellants/pressurants are loaded until launch.	No pre-launch environmental controls are required for cryogenic Tugs for safety purposes. A ground GN purge capability for the payload bay should be provided by Orbiter/GSE design (interface requirement).
15. Purge provisions shall be available to neutralize propellant leaks during and after propellant servicing and after Orbiter landing.	A GHe purge is provided through leakage containment membranes on both propellant tanks and all disconnect panels.
16. Ventilation shall be provided under positive pressures for all propellant loading operations to prevent accumulation of hazardous vapors.	Ventilation of deployment adapter is provided by open structure design. No other interface equipment encloses a sufficient volume to pose a significant hazard.
17. Transfer lines shall be purged after the transfer of hazardous fluids.	H_2 and O_2 transfer lines and N_2H_4 relief line are purged via the Tug He system.
18. Integrated checkout and testing of safety critical Tug systems shall be conducted prior to installation in the Orbiter and verified after installation into the Orbiter.	Integrated checkout and testing prior to installation in the Orbiter must be accomplished as part of ground operations procedures. After installation in the Orbiter, the interfacing systems that are used in monitoring/control of safety critical functions will also be used in statusing most functions. Some functions, such as Tug rotation, APS operation, cannot be verified after installation in the Orbiter.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
<u>Tug/Orbiter Requirements</u>	
19. Tug pressurized systems shall have a maximum operating pressure helium leak check before installation into the Orbiter payload bay and an inert gas leak check before loading propellants.	Requirement for maximum operating pressure He leak check prior to Tug installation into an Orbiter is outside the scope of the Interface Study. An inert gas leak check can be conducted via the propellant fill and drain interface while the Tug is in the Orbiter.
20. Internal attitude control signal of the Tug shall be capable of being checked for accuracy by the Orbiter crew before release.	Tug safety controls/monitors are provided for all safety critical functions including ACS functions, by the Tug Data Bus Monitor signals and by analogue instrumentation (hardwired) for Caution and Warning functions.
21. Provisions shall be made to pressurize propellant tanks of Tug to avoid implosion during return flight.	Tug is pressurized via the He pressurization system prior to return flight. He storage capability is provided by Tug peripheral equipment.
22. Tug propellant tank and pressure vessel design factors of safety shall be as specified in Space Shuttle System Payload Accommodations JSC 07700, Vol. XIV, Rev. B, December 21, 1973.	Design factors of safety are in accordance with Rev. C of the referenced document. These same requirements have been applied to all interface equipment.
23. Pressure vessels and tanks shall conform with and be maintained under a fracture mechanics control program.	It is intended that the He tanks required for propellant tank repressurization and/or abort dump be subjected to a fracture mechanics program. Program to be developed during phase C/D.
24. Pressure lines and vessels shall be clearly coded to identify contents, capacity and operating pressure.	Design detail. Requirement should be implemented during phase C/D design.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
25. Flexible sections of pressure hose disconnects shall be restrained so that a failure will not cause damage to adjacent equipment or injury to personnel.	All pressure hose disconnects are restrained by the disconnect panels.
26. A structural interface shall be provided between the Tug and the Orbiter payload bay support points that transmits the Tug and Spacecraft loads into the Shuttle structure with a 25% margin of safety under the most adverse Shuttle design loads, excluding crash loads which are ultimate.	Tug support adapter/attach points/latches are designed to withstand most adverse Shuttle design loads with the required 25% safety margin.
27. Provision shall be made to detect incipient failures of tanks containing hazardous fluids or high pressures to the greatest extent possible.	Interface equipment subject to this requirement are the He tanks. It is intended that they be subjected to a fracture mechanics program during phase C/D.
28. A redundant relief capability shall be provided for the Tug tanks which automatically limits the maximum pressure.	Redundant vent valves are provided for the H_2 and O_2 propellant tanks. A single disconnect fitting is provided at the Tug/Orbiter interface for each pair of valves. The N_2H_4 and He pressurant systems incorporate both relief and dump capability.
29. Tug propellant drain and vent interface with the Orbiter shall permit main propulsion system propellant venting, and emergency detanking (whether Orbiter is horizontal or vertical attitude).	Complete tank drain can be accomplished only with the Tug in vertical attitude. Since both H_2 and O_2 will be dumped during an abort, there is no need for draining these propellants while Tug is in horizontal attitude. Propellant tank vents are functional for both vertical and horizontal attitudes of the Tug. Result of Trade Study, see Figure 4.7-1.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
<u>Tug/Orbiter Requirements</u>	
30. A capability shall be provided for the Orbiter crew to dump hazardous Tug fluids and vent Tug pressurants overboard within the time constraints imposed by an abort situation. This capability shall be available with the payload bay either open or closed.	Tug main propellants can be dumped within 200 seconds. This assures that propellant dump can be completed prior to reaching a point where the atmospheric pressure can form a flammable mixture with the dumped H_2. Tug pressurants and RCS propellants can also be dumped during an abort.
31. Tug cryogen tank thermal protection systems shall be designed to minimize (below ignition regimes) accumulation of flammable fluids resulting from propellant system leakage.	Provisions are made at the oxygen and hydrogen disconnect panels for overboard venting of the leakage containment purge gases. Thus any leaks that should develop in the hydrogen or oxygen tanks will be carried safely away.
32. Any Tug supplied deployment/retrieval system shall provide positive control of the Tug movements during translation out of or into the payload bay. It shall be designed for fail operational/fail safe operation or shall be jettisonable to preclude exceeding the Tug stowage envelope.	Dual motors are used in each of the two deployment actuators. In the event of a jammed actuator, the design allows for disconnection of the failed actuator through the RMS or EVA and continued Tug deploy/restow operations.
33. Tug fluid fill and drain umbilical disconnects shall have positive sealing at disconnect. Provisions shall be made to prevent pressure buildup in the system.	Triple seals, backed up by an He purge, are used at all disconnects that can contain hazardous fluids.
34. Leakage sources of the Tug or its equipment shall be minimized by use of all welded or brazed construction where practical.	Design detail. Requirement should be implemented during phase C/D design.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
35. Components and assemblies selected for the Tug shall be marked or tagged to identify their manned-mission application.	Design detail. Requirements should be implemented during phase C/D design.
36. Cleanliness requirements and fluid contamination for propellants and propellant systems shall be controlled and monitored to assure that the STS safety is not jeopardized.	All interface fluid disconnects incorporate helium purges, shut-off valves, or self-sealing features that prevent contamination of fluid lines.
37. Hypergolic propellant tanks, fuel and oxidizer, shall be pressurized from separate pressure sources.	No hypergolic propellants are contained in present Tug baselines.
38. A leak sensing system shall be utilized to detect leaks at the deployment adapter interface.	Leak sensing is accomplished in the purge cavity of the disconnect panels.
39. Tug propulsion system start sequence logic status and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management Interface. Transmission shall be through hardwire while within the Orbiter bay but once outside it may be transmitted directly from the Tug.	Safety critical valve position data are transmitted to Orbiter crew via hardwire. Transmittal of start sequence logic status is by data bus and RF link.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
40. Systems containing fluids that are subject to decomposition through contamination or loss of passivation (such as monopropellants) shall be safed by appropriately sized and located vents for the worst case decomposition rate.	Propellant systems that contain fluids that are subject to decomposition must be designed to accommodate the worst case decomposition rate that can be expected during fill. The interface design provides for overboard (external to Orbiter) venting to accommodate any overpressures that may occur due to mild contamination or loss of passivation.
41. Message signals for Tug system, by hardwire and RF telemetry, shall be provided at the Shuttle Data Management System Interface. Measurements shall include Tug latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve psoitions, temperature and pressure measurements, and failure indications. This information should also be available prior to retrieval.	Interface provisions have been made to allow transmittal of safety critical data by hardwire when Tug is in payload bay or otherwise via RF telemetry data link.
42. Tug critical command and control circuitry shall be designed to be fail operational/fail safe as a minimum.	Interface design provides for dual redundant digital data link between Orbiter and Tug.
43. Tug batteries shall have the case vented through relief valves into Orbiter overboard battery venting system.	Tug overboard battery venting will be via the hydrogen vent line interface.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
<u>Tug/Orbiter Requirements</u>	
44. Electrical umbilical disconnects between the Orbiter and the Tug and between the Tug and Spacecraft shall be separated from hazardous fluid disconnects, shall be qualified as explosion proof, and shall not have power applied during disconnect.	Electrical disconnect panels are separate from fluid disconnect panels. The electrical disconnects should be qualified as explosion proof during phase C/D. It is intended that the Tug be switched to internal power and that power at disconnects be shut down prior to disengagement.
45. Power circuits shall be separated from critical pyrotechnic circuits within a cable or wire bundle.	Design detail. Must be implemented during detail design (phase C/D).
46. Tug structure shall be grounded to Orbiter, structure to prevent electrostatic charge buildup and an electrical shock hazard. Within the Tug, grounding shall be such as to preclude an electrical shock.	Tug structure to be grounded to Orbiter via a grounding pin in one of the electrical disconnects. Grounding within the Tug is considered to be a Tug contractor responsibility.
47. Safety critical electrical and electronic components shall be potted, hermetically sealed or similarly protected against the effects of liquid leakage, moisture condensation, vibration and arcing contacts.	Tug structure shall be grounded to the Orbiter and the Spacecraft via grounding pins in the electrical disconnects.
48. Capability shall be provided for static discharge between Tug and Orbiter and between the Tug and Spacecraft.	Safety critical switches are interlocked with enable switches to preclude inadvertent actuation of safety systems. The enable switches are guarded with switch covers to preclude inadvertent actuation.
50. Tug shall have a means of shutting off its electrical power under emergency conditions.	Tug electrical power can be shut down via commands transmitted on the digital data link.

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
51. Electrical wiring must not be routed against or around sharp edges.	Design detail. To be implemented during phase C/D.
52. Electrical wiring must not be in contact with flammable fluids.	Electrical connectors are routed through disconnect panels that are separate from fluid panels.
53. Electrical circuits which will be cut by guillotine cutters must be deadfaced.	No guillotine cutters are used on the present Tug/ Orbiter of Tug Spacecraft interface designs.
54. Provisions shall be included for Tug Caution and Warning functions which will provide both audible and visual warning to Orbiter personnel of hazardous situations while the Tug is in the Orbiter payload bay or being deployed.	Tug Caution and Warning data is displayed on the Caution and Warning panel. Safety critical caution and warning functions are described in Section 4.7.1-3.
55. Only GN_2 shall be permitted to be dumped into Orbiter payload bay from the Tug and then only under controlled conditions.	The only Tug pressurant is He. During ground pressurization of the He system, any over pressurization of the He system will be vented external to the Orbiter via a relief valve on the GSE. If an over pressurization of the He system should take place after the GSE is disconnected, the He pressurant can be dumped through an externally vented dump line. (Note: Some He flows into the payload bay as a normal sequence of insulation purging. (See Section 4.5 of the report for details).

Table 4.7-1. Tug/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Orbiter Requirements	
56. Artificial sources of radiation from the Tug shall be shielded, oriented, otherwise limited to prevent exceeding flight crew dosimetry requirements as established by the NASA radiation constraints panel. Compliance with critical equipment radiation requirements shall also be maintained.	No radiation sources are used on present Tug designs.

Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
1. Spacecraft will provide Caution and Warning data to the Orbiter and Crew for safety critical functions while aboard or in the vicinity of the Orbiter.	Provisions for Spacecraft Caution and Warning functions are provided by both hardwire and payload telemetry downlink.
2. Provisions shall be made to confirm that all safety critical Spacecraft/Tug and Spacecraft/Orbiter interfaces are securely concerned.	Spacecraft/Tug interfaces are powered via a C&W arm safe switch and are monitored for safe status via the hardwire when attached and when detached via the payload telemetry downlink. Spacecraft/Orbiter interfaces are considered to be the responsibility of Orbiter/Spacecraft contractors.
3. Any Spacecraft subsystem operation which impacts safety during the launch and entry phases shall be monitored from the Orbiter flight station.	Interface provisions for monitoring Spacecraft safety critical functions are provided by the payload telemetry downlink detached and via hardwire signals when attached.
4. A means shall be provided for controlling the venting of Spacecraft fluids while in the Orbiter payload bay.	Relief provisions for payload hazardous fluids (N_2H_4) can be provided via the Tug N_2H_4 relief line. Other hazardous fluids must be relieved via a separate Spacecraft/Orbiter interface.
5. Provisions shall be made for verifying critical Spacecraft systems readiness before activation.	Spacecraft caution and warning signals are transmitted via Tug telemetry. Specific spacecraft safety critical functions must be identified by the spacecraft contractor.

Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
6. All electrical, emchanical and fluid connections between the Spacecraft and Tug and/or Orbiter shall be designed to be fail safe.	Electrical signals are via dual redundant links; Tug/Adapter latches are two-failure tolerant; fluid connections utilized dual and triple redundant seals. Tug to Spacecraft latches and umbilicals are the responsibility of the Tug contractor.
7. Systems containing fluids that are subject to decomposition through contamination or loss of passivation (such as monopropellants) shall be safed by appropriately sized and located vents for the worst case decomposition rate.	Spacecraft containing N_2H_4 propellants can be relieved via the Tug N_2H_4 vent interface. Other hazardous fluids must incorporate separate relief provisions via a Spacecraft/Orbiter interface.
8. A redundant relief capability shall be provided for Spacecraft tanks which automatically limits the maximum pressure. Relief shall be through the Orbiter vent system overboard. Overpressure relief capacity shall be redundant to vent capacity. (When vent capability is provided, relief capability need not be redundant.)	Relief/vent valve provisions for Spacecraft are considered to be the responsibility of the Spacecraft contractor. Vent/relief line interfaces are provided by 7 above.
9. Spacecraft propellant drain and vent interface with the Orbiter shall permit Spacecraft main propulsion system propellant venting and emergency detanking (whether Orbiter is in horizontal or vertical attitude) until launch commit, with the Orbiter payload bay doors closed or open.	Interfaces associated with Spacecraft propellant vents/drains are considered to be the responsibility of the Spacecraft/Orbiter contractors.

Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
10. Spacecraft fluid fill, drain, and vent umbilical disconnects shall have positive sealing at disconnect, whether the action is intentional or accidental. Provisions shall be made to prevent pressure build-up in the system. Dual valving shall be provided to ensure emergency drain if one valve should fail.	Same as 9 above.
11. Spacecraft cryogen tank thermal protection systems shall be designed to minimize (below ignition regimes) accumulation of flammable fluids resulting from propellant system leakage.	Spacecraft containing liquid hydrogen and/or liquid oxygen can have their thermal protection systems vented via the corresponding thermal protection system vents in the Tug. Other potentially hazardous cryogens that are not compatable with hydrogen or oxygen systems must be vented through a separate interface.
12. Propulsion system safety critical data, start sequence logic status and valve positions shall be monitored and signals provided to the Orbiter for corrective action to be taken.	Spacecraft safety critical data can be transmitted via the payload telemetry downlink. Use of an arm safe switch, controlled by the S/C C&W panel has been recommended for systems, which must remain dormant in the Shuttle vicinity.
13. Provisions shall be made to verify completion of main engine propulsion system safing prior to retrieval.	Same as 12 above.

Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
14. Message signals from Spacecraft systems shall be provided at the Shuttle Data Management System Interface. Measurements shall include at least Spacecraft latched/released indication, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications.	Same as 12 above.
15. Spacecraft critical command and control circuitry shall be designed to be fail-operational/fail safe as a minimum.	Spacecraft command and control circuitry is Spacecraft responsibility. Data link to circuitry is provided by redundant Payload Digital Data link.
16. Automatic event sequencing programs and automatic controls whose actuation could affect flight personnel safety shall be operative only by the Orbiter, or by ground control enabling switches (command override), e.g., pyrotechnic sequences, automatic deployment sequences, etc.	Safing of event sequencing and automatic controls is Spacecraft responsibility. Operation/control of Spacecraft by Orbiter can be accomplished via payload digital data link. Spacecraft systems/operations involved should be arm/safed in Orbiter payload C&W panel.
17. Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification.	Safety status interface is provided by hardwire plus payload telemetry downlink.

Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
18. Spacecraft propulsion system start sequence logic status, and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management System Interface. The transmission shall be through Tug hardwire while within the payload bay but, once outside, it may be transmitted either directly from the Spacecraft or via the Tug telemetry system.	While within the payload bay, status of safety critical Spacecraft equipment is provided by hardwire plus payload telemetry downlink. Outside of Orbiter, Spacecraft data transmitted by RF is considered to be Spacecraft responsibility.
19. Spacecraft shall have a means of shutting off their electrical power under emergency conditions.	Signal to shutdown Spacecraft power can be transmitted through payload digital data link. Spacecraft design must incorporate shutdown capability.
20. Safety critical control circuits shall be capable of being verified.	Payload safety critical circuits can be verified via payload telemetry downlink.
21. Provisions shall be included for Spacecraft Caution and Warning functions which will provide both audible and visual warning to Orbiter crew of hazardous situations while the Spacecraft is aboard the Orbiter or being deployed.	Spacecraft Caution and Warning data can be transmitted to Orbiter crew via payload telemetry downlink. Specific cautions and warnings associated with spacecraft operations must be identified by Spacecraft contractors.

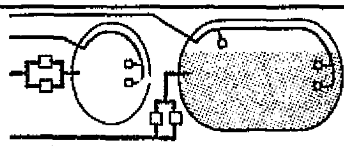
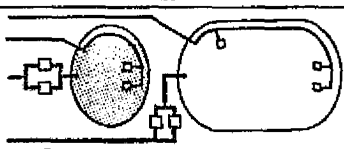
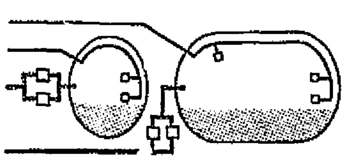
Table 4.7-2. Spacecraft/Orbiter Interface Safety Criteria (contd)

CRITERION	RESOLUTION
Tug/Spacecraft Requirements	
22. Means shall be provided to control toxic, flammable explosive and corrosive substances aboard Spacecraft and to preclude their accumulation in or venting into the Orbiter payload bay. The maximum operating temperature shall be taken into consideration as a generative source of hazardous fluids.	Payload N_2H_4 can be relieved via Tug N_2H_4 relief line. Other Spacecraft hazardous fluids must be vented/relieved via a Spacecraft/Orbiter interface.
23. Integrated checkout and testing of safety critical Spacecraft systems shall be conducted prior to installation on the Tug and verified after installation into the Orbiter.	Spacecraft verification after installation in the Orbiter can be achieved via the payload digital data link. Specific test parameters must be identified by the Spacecraft contractors.
24. Spacecraft shall have capability for the Orbiter crew to dump hazardous fluids and vent pressurants overboard within TBD seconds in an abort situation.	Spacecraft fluid dump capability is considered to b a Spacecraft/Orbiter responsibility. Interface considerations associated with hazardous fluid dump must be mutally resolved by NASA, Orbiter contractor, Spacecraft contractor, and the Tug contractor.
25. Electrical umbilical disconnects between the Orbiter and the Spacecraft and/or Tug shall not have power applied during disconnect.	Tug will be switched to internal power prior to disconnect. There will be no power applied across interface during Tug/Orbiter separation or recovery. It is assumed that this same procedure will apply to Tug/Spacecraft separation.

The tank configurations in this figure represent the following capabilities: 1) horizontal vent capability for hydrogen tank; no horizontal drain, and 2) no horizontal vent or horizontal drain capability for the oxygen tank. The possible conditions that would require ground draining/venting of the hydrogen or oxygen tanks are listed along with the safety/operations consequences that are associated with those conditions. The probabilities of occurrence for each condition are also presented to indicate the expected frequency of occurrence. These probabilities are based on conservative success probability estimates of 0.999 for each leg in the redundant dump valve or abort dump pressurization systems. The probability that both legs will fail during an attempted abort is $P = 2R-R^2$, where R is the reliability of a single leg.

The safety/operations consequences of each failure indicate that failure of the hydrogen dump system, or failure in the dump pressurization system, can result in turnaround time delays. These turnaround delays, should they occur, could be eliminated by the addition of a horizontal dump system at a weight penalty of 130 pounds. A failure of the oxygen system dump system has more serious consequences. The present Tug oxygen tank design is incapable of maintaining structural integrity during a fully tanked landing. This consequence can only be avoided by increasing the structural strength of the oxygen tank at a weight penalty 171 pounds.

The two most important points indicated in the analysis are that 1) the probability that any negative condition will occur is low, and 2) the only serious consequence is related to the inability of the oxygen tank to retain structural integrity if a landing is attempted with a full tank. This second point is related only to tank structure itself and is independent of whether or not a horizontal drain is provided.

CONDITION	SAFETY/OPERATIONS CONSEQUENCE	TUG WEIGHT PENALTY TO AVOID CONSEQUENCE
 RTLS ABORT; REDUNDANT LH_2 DUMP VALVES FAIL ($P < 1$ PER 10^6 ABORTS)	• TANK STRUCTURE OK • HORIZONTAL VENT ALLOWS BOILOFF • TURN-AROUND TIME DELAY	78 LB (2 VALVES/LINES)
 RTLS ABORT; REDUNDANT LO_2 DUMP VALVES FAIL ($P < 1$ PER 10^6 ABORTS)	• LO_2 TANK STRUCTURE FAILS ON LANDING	171 LB (STRUCTURE, 2 VALVES/LINES)
 RTLS ABORT; REDUNDANT ABORT DUMP PRESSURIZATION SYSTEMS FAIL ($P < 1$ PER 10^6 ABORTS)	• > 65% OF LH_2 DUMPED • > 80% OF LO_2 DUMPED • TANK STRUCTURES OK • LO_2 VERTICAL VENTS ALLOW LO_2 BOIL-OFF • LH_2 HORIZONTAL VENT ALLOWS LH_2 BOIL-OFF • TURN-AROUND TIME DELAY	52 LB (2 LO_2 VALVES/LINES) 78 LB (2 LH_2 VALVES/LINES) 130 LB

$\Sigma = 301$ LB (790 LB PAYLOAD)

Figure 4.7-1. Drain/Vent Trade Study Results

The conclusion is that the weight penalties associated with the addition of horizontal drain capability to the hydrogen and oxygen tanks are not justified.

With respect to Tug/Orbiter safety requirement 33, the fluid fill and drain system is also used for propellant dumping. Consequently, a positive seal at the disconnect for this concept would not be appropriate. Since this line is drained and purged after propellant loading has been completed, the line will contain no liquid propellants at time of disconnect.

4.7.1.2 Verification of Tug/Orbiter Interconnects. The capability of verifying that Tug/Orbiter interconnects have been safely made is of paramount importance in assuring interface safety. Verification of electrical interfaces can be accomplished with relative ease through the use of electrical panel engagement switches and by verification of the connection with test signals.

Verification that critical fluid system interface connections have been safely made is a more complex problem. This is especially true when the verification must be made after Tug recovery. To provide a means of assuring that the fluid connections have at least fail-safe capability, the interconnect design concepts in Figure 4.7-2 have been developed. In these concepts, redundant fluid seals are used at the primary interconnect surface. In addition to these seals, a purge seal is provided that effectively results in a third backup seal. By monitoring the He flow (or pressure) in the purge cavity, the helium purge seal can be verified. By monitoring the purge gas for the presence of the fluid being contained (such as H_2), verification can be made that at least one of the fluid seals is operational. These design concepts thus allow the flight and/or ground crews to verify that the fluid interconnect is at least fail-safe prior to beginning the next major operation.

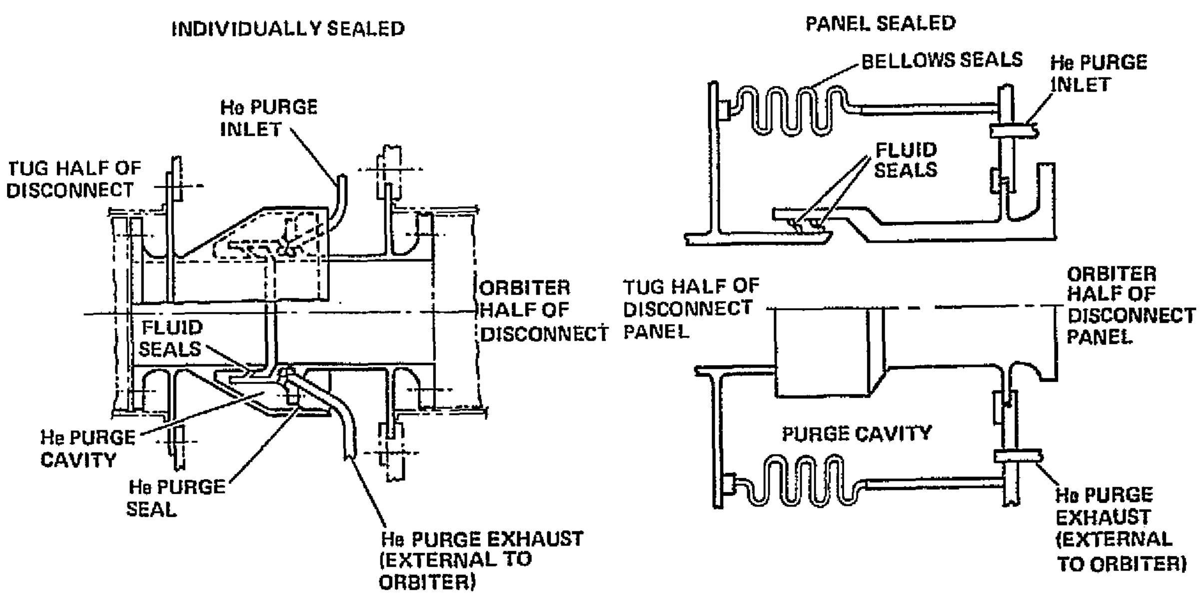


Figure 4.7-2. Fail-Safe Verification of Interconnects

4.7.1.3 Caution and Warning Application. The basic philosophy used in the C&W system is that caution and warning indicators be used only when a threat to the safety of the Orbiter/crew has manifested itself and immediate crew action or attention is required to control the hazard. Warnings are intended to identify imminent dangers to the crew that require direct and immediate corrective actions. Cautions indicate that a hazardous condition will exist if 1) a hazardous condition is not corrected before entering the next mission phase, or 2) an equipment failure has occurred during a critical maneuver and a single backup equipment is being relied on to preclude a catastrophic consequence.

Advisory data is used to indicate loss of redundancy and/or possible loss of mission objectives. The data is not intended to elicit immediate responses from the crew. The philosophy here is that advisory data will be evaluated by the crew at specific points during the mission and that appropriate action will be taken by the crew before proceeding to the next mission phase.

As indicated in Figure 4.7-3, the functions of the Caution, Warning, and Advisory data must be aligned with the mission phases and discrete events that occur in the course of a Tug mission. Advisory data is called up by the Mission Specialist at discrete points in the mission. The advisory data is checked against the mission rules for a particular mission and a decision made as to whether or not the mission should be continued

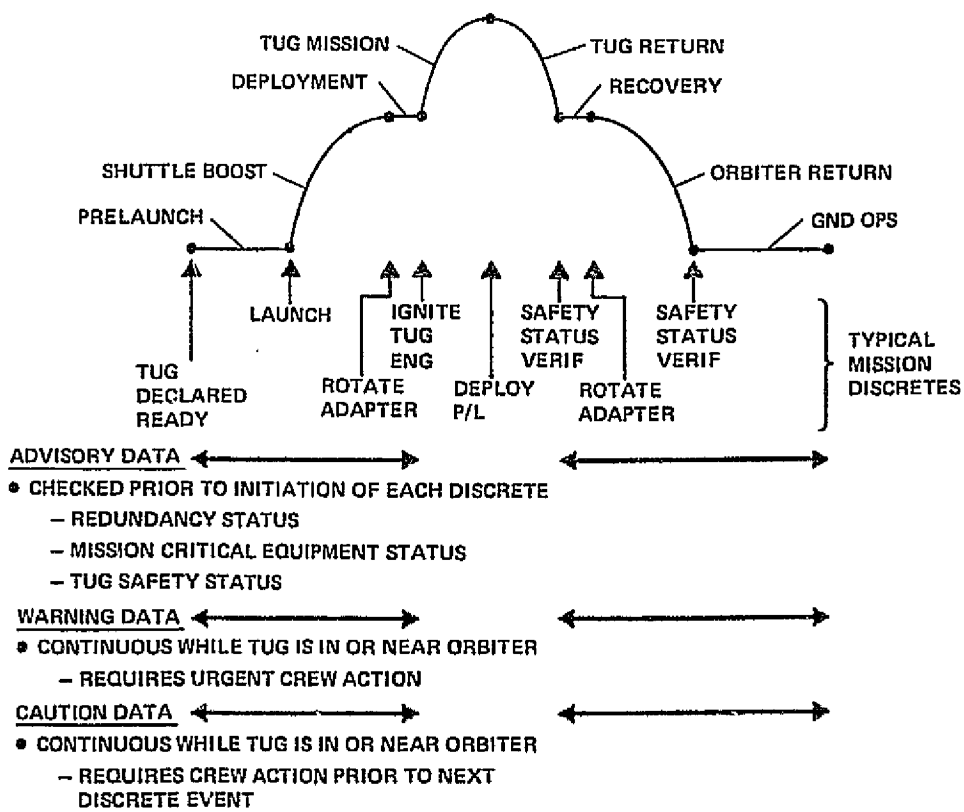


Figure 4.7-3. Caution and Warning Application

or aborted. Warning data is continuously available while the Tug is in the payload bay or is in the near vicintiy of the Orbiter.

Caution data is also continuously available while the Tug is in or near the Orbiter. The caution data is, however, event-sequence oriented. For example, when the Tug/adapter latches are open during the deployment sequence, the condition is obviously normal and the caution light should remain extinguished. If, however, an attempt is made to rotate the Tug back into the payload bay with any of the latches open, the caution light should illuminate to indicate that an unsafe condition is being approached. The caution light indicates that this condition must be resolved before entering the next mission phase; i.e., Orbiter return and landing.

Tug hazard analyses (reference Space Tug Systems Study, MAS 8-29676) and the interface Failure Modes and Effects Analyses (Table 4.7-4) were reviewed to identify which potential hazards required immediate crew action (warnings) and which required crew action prior to performing the next mission discrete event (cautions). The conditions that require warning and caution signals identified in the analysis are contained in Table 4.7-3.

Table 4.7-3. Conditions Requiring C&W Signals

Warning	Caution	
N_2H_4 Tank Overpressure	APS ISO Vlv Open	Deploy ArmSafe Armed
LO_2 Tank Overpressure	ME ISO Vlv Open	APS Cluster Failed
LH_2 Tank Overpressure	Tug/Adapter Latch Open	APS PRI Elec Failed
LO_2 Tank Underpressure	Tug/Support Latch Open	APS Prop Low
LH_2 Tank Underpressure	Tug/Orb Disc Open	H_2 in LCM
	ME Arm/Safe Armed	H_2 in P/L Bay
	APS Arm/Safe Armed	N_2H_4 in P/L Bay

Each warning signal will illuminate a master warning light on the C&S panel and cause the warning tone to sound continuously (the tone can be reset to OFF by the crew). A specific warning light is also illuminated to indicate the hazardous condition that requires crew attention. The warning also appears on the CRT along with a description of the crew action to be taken. A caution signal will illuminate the master caution light and cause the warning tone to sound intermittently. The specific cautionary data will appear on the CRT along with a description of the crew actions to be taken.

To determine how each caution and warning signal should be related to each mission phase, logic diagrams, such as the typical case in Figure 4.7-4, were used.

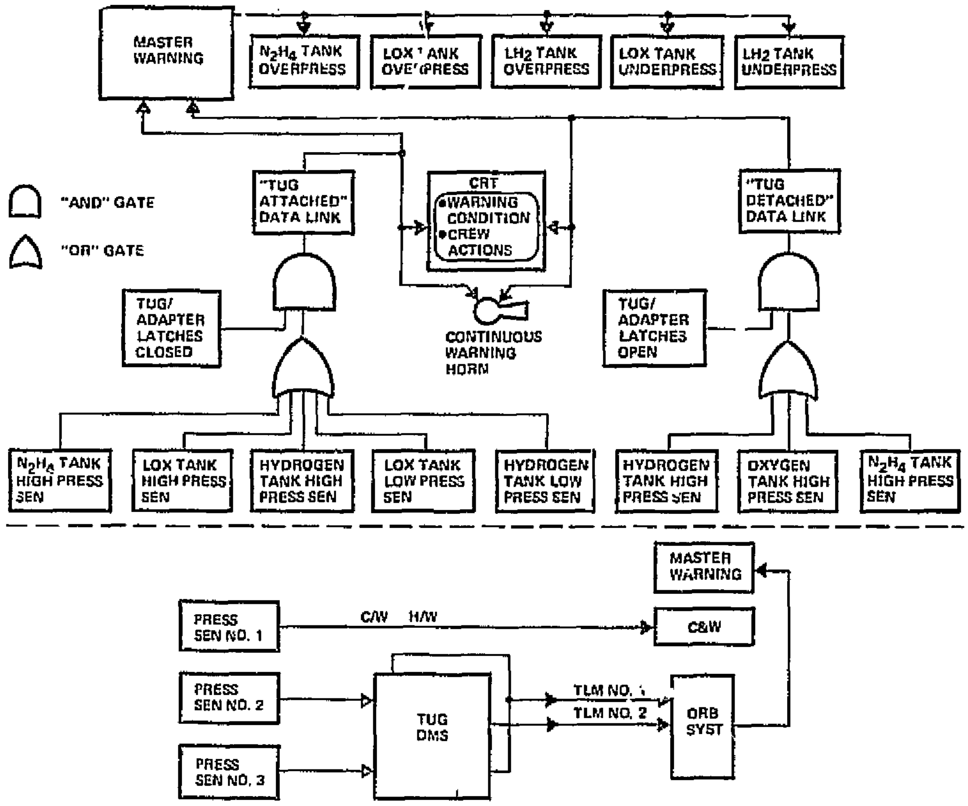


Figure 4.7-4. Typical Master Warning Implementation

The diagram on the upper half of this figure indicates the logic associated with the warning system. The logic symbols are the same as those used in fault tree analyses. Note that warning indications can be initiated by either of two paths. One is the Tug attached path and the second is the Tug detached path. The crew actions that must be taken (and that appear on the CRT) will be different depending on whether the Tug is attached or detached. For example, with the Tug attached, an LH_2 tank overpressure warning may require override control of the vent valves or initiation of propellant dump. If the same warning appears while the Tug is detached, the crew action would be to immediately achieve a safe separation distance between Orbiter and Tug. The avionics equipment required to implement the caution and warning capability are described on the lower half of the figure.

The logic diagram approach to implementation of the caution function is similar to that used on the warning system. If the conditions described by the logic diagram are met, the caution light will illuminate and the warning tone will sound intermittently to indicate a potential hazard. The fault that causes the caution will appear on the CRT with the crew action required to correct the condition. Typical master caution logic is illustrated in Figure 4.7-5. The avionics equipment associated with the caution system is described on the lower half of the figure.

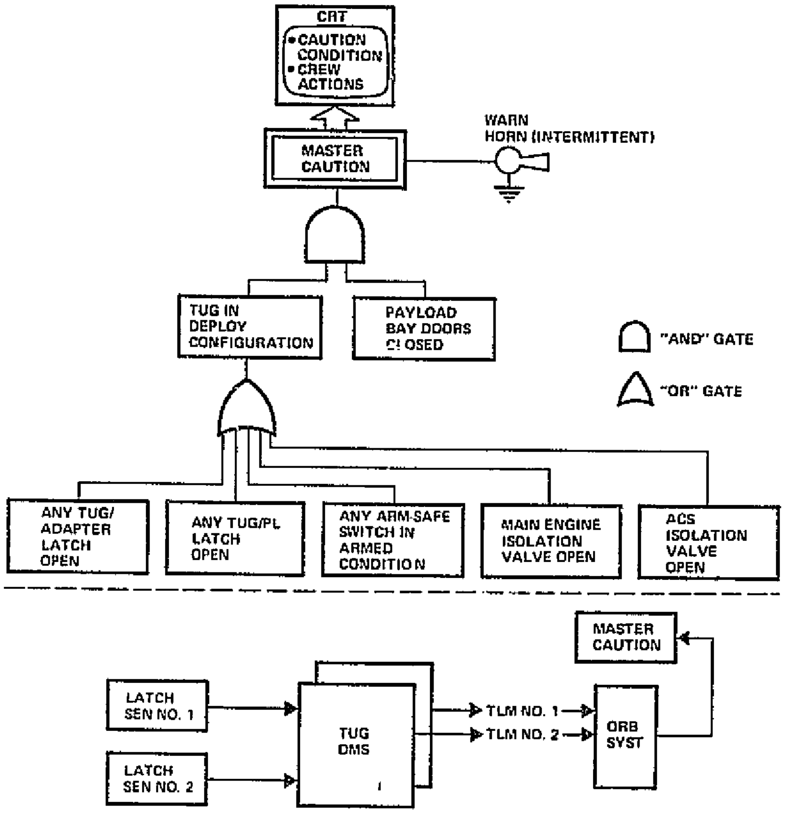


Figure 4.7-5. Typical Master Caution Implementation

4.7.2 RELIABILITY. The reliability of the interface design candidates were evaluated to assure that the selected interface designs will not compromise the overall reliability of the Space Tug. This was accomplished by conducting a failure modes and effects analysis (FMEA) on the interface designs to determine if single failure points exist in the design that could 1) compromise crew safety, or 2) cause mission loss. In conducting this analysis, considerable attention had to be given to the detailed Tug designs as well as to the interfaces themselves. That is, to evaluate the effects that potential interface failure modes can have, it was necessary to evaluate the failure effect with respect to the entire Shuttle/Tug system. Consequently, the resultant output of the FMEA includes interface design modifications and recommendations for Tug designs that will improve the overall safety and reliability of the system.

The failure modes and effects analyses conducted during the Tug interface study are contained in Table 4.7-4. As suggested in this table, the FMEA was first conducted on the early Tug and Tug interface designs. As potential single-point failures were identified, the Tug and Tug interface designs were modified to eliminate those single-point failures.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B)

SUBSYSTEM: He Press & Controls

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He High Pressure Fill Valve No. 1 and No. 2	T-H-001 T-H-002	N.C. Parallel Charge Valves Fail closed - either valve can fail closed Fail open or leakage - valves in series with deployment adapter D/A-H-001	 NI NI	None required	 NI NI
He Vent Valve No. 1 and No. 2	T-H-003 T-H-004	N.C. Series Vent Valves Fail closed - either valve failure will shut down one leg of system, but parallel T-H-005/burst disk is safety backup Fail open or leakage - either valve can fail open and system will continue to function	 NI NI	None required	 NI NI
He Vent Valve No. 2	T-H-005	N.O. In Series with Burst Disk Fail open or leakage - normal safe condition Fail closed - shuts down one leg of the parallel vent system and relies on T-H-003 and T-H-004. Fail to close after burst disc - loss of all He control and purge capability. Although the burst disc will prevent the He bottles from blowing, not being able to reshut the vent line by T-H-005 failure to close would deplete all Tug He. However, not a single failure point. He overpressure most likely on the ground.	 NI NI NI	None required	 NI NI NI
He APS Press Valve No. 1 and No. 2	T-H-006 T-H-007	N.O. Parallel Valves Fail open or leakage - would pressurize the APS N_2H_4 fluid system - but all outlets have series redundant shutoff. Fail closed - either valve could fail closed.	 NI NI	None required	 NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: He Press & Controls

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He APS Press Vent Valve No. 1 and No. 2	T-H-008 T-H-009	N.C. Series Vent Valve Fail closed - either valve failure will shut down one leg of vent system, but parallel T-H-010/burst disc is safety backup. Fail open or leakage - either valve can fail open and system will continue to function.	 NI NI	None required	 NI NI
He APS Press Vent Valve No. 3	T-H-010	N.O. In Series with Burst Disc Fail open or leakage - normal safe condition. Fail closed - Shuts down one leg of parallel vent system and relies on T-H-008 and T-H-009.	 NI NI	None required	 NI NI
He LO_2 Fuel Tank Pressure Valves No. 1 and No. 2	T-H-011	N.C. Parallel valves feeding individual regulators in series with valves Fail closed - Either leg can fail closed. Fail open or leakage - regulator will continue to maintain tank pressures within operating minimum. Problem during safing where venting propellant tank to low pressures to evacuate tank would also deplete onboard He supply. Loss of He would drop out He controls before Tug retrieval by Orbiter; i.e., N.C. vent valve controls would lock up tank vent capability. Changes some reconnect sequencing but not a safety inhibiter.	 NI Operational Constraint	Shut-off valves have been added in series with the pressure regulators. A failed open or leaking regulator can be individually shut down. If failure occurs after Tug/Orbiter separation, Tug could be lost.	 NI NI
He GH_2 Vent Valve Control No. 1 and No. 2	T-H-013 T-H-014	N.C. Parallel Control Valves Fail closed - either leg can fail closed. Fail open or leakage - will hold the vent valve open, venting the propellant tank. Depending upon time frame during operation, the venting fluid may freeze to slush/solid and present an abort problem. Also presents a venting problem after landing. Recommend added series valves in each parallel leg and interconnect; i.e., quad redundant.	 NI Operational Problem to Potentially Catastrophic	Each of the vent control valves has been backed up with an additional control valve to preclude leakage/fail open problem.	 NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: He Press & Controls

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He LH_2 Fill, Drain & Dump No. 1 and No. 2	T-H-015 T-H-016	N.C. Parallel Valve Control of Parallel Propellant Valves Fail closed - either leg can fail closed. Fail open or leakage - will hold the propellant valves open, dumping propellants and all pressurization He gas. Not only will the H_2 tank be completely vented, but the onboard He supply could be depleted in the systems attempt to maintain structural integrity of the main tank. Recommend added series valves in each parallel leg and interconnect; i.e., quad redundant.	NI Operational Problem to Potentially Catastrophic	Backup, normally open, dump valve has been added on adapter. If one of the primary dump valves fails open, backup valve can be closed to preclude loss of propellants/pressure. Butterfly flapper on backup valve is biased toward the open position to allow continued dump capability if the flapper should fail. If primary dump valve should fail open after Tug/Orbiter separation, Tug could be lost.	NI
He RL10 Engine Prevalve (Tank Isolation Valve)	T-H-017	N.C. - In series with Engine Prevalve T-H-016 Fail closed - no propellants to engine. Fail open - allows propellants to enter feed duct from main tank to engine inlet. T-H-17 acts as backup for duct failure.	NI NI	None required for safety.	NI NI
He LO_2 Fill, Drain & Dump Valve Control No. 1 and No. 2	T-H-019 T-H-020	N.C. Parallel Valve Control of Parallel Propellant Valves Fail closed - either leg can fail closed. Fail open or leakage - will hold propellant valves open, dumping propellants and all pressurization He gas. Not only will the O_2 tank be completely vented, but the onboard He supply could be depleted in the systems attempt to maintain structural integrity of the main tank. Recommend added series valves in each parallel leg and interconnect; i.e., quad redundant.	NI Operational Problem to Potentially Catastrophic	Backup, normally open, dump valve has been added on adapter. If one of the primary dump valves fails open, backup valve can be closed to preclude loss of propellants/pressure. Butterfly flapper on backup valve is biased toward the open position to allow continued dump capability if the flapper linkage should fail. If primary dump valve should fail open after Tug/Orbiter separation, Tug could be lost.	NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: He Press & Controls

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He RL10 LO_2 Engine Prevalve (Tank Isolation Valve)	T-H-021	N.C. - In series with Engine Prevalve T-H-028 Fail closed - no propellants to engine. Fail open - allows propellants to enter feed duct from main tank to engine inlet. T-H-021 acts as backup for duct failure.	 NI NI	None required for safety.	 NI NI
He LO_2 Tank Pressurization Valve No. 1 and No. 2	T-H-022 T-H-023	N.C. Parallel valves feeding individual regulators in series with valves Fail closed - either leg can fail closed. Fail open or leakage - regulator will continue to maintain tank pressures within operating minimum. Problem during safing where venting propellant tank to low pressures to evacuate tank would also deplete onboard He supply. Loss of He would drop out He controls before Tug retrieval by Orbiter; i.e., N.C. vent valve controls would lock up tank vent capability. Changes some reconnect sequencing but not a safety inhibitor.	 NI Operational Constraint	Shutoff valves have been added in series with pressure regulators. Failed open or leaking regulator can be individually shut down.	 NI NI
He GO_2 Vent Control No. 1 and No. 2	T-H-024 T-H-025	N.C. Parallel Control Valves Fail closed - either leg can fail closed. Fail open or leakage - will hold the vent valve open, venting the propellant tank. Depending upon time frame during operation, the venting fluid may freeze to slush/solid and present an abort problem. Also presents a venting problem after landing. Recommend added series valves in each parallel leg and interconnect; i.e., quad redundant.	 NI Operational Problem to Potentially Catastrophic	Each of the vent control valves has been backed up with an additional control valve to preclude leakage/fail open problem.	 NI NI
He RL10 LH_2 Prevalve Control	T-H-026	N.C. in Series with T-H-017 Fail closed - no propellant to engine. Fail open or leakage - slightly higher He safing purge rate through engine.	 NI NI	None required for safety.	 NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: He Press & Controls

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He RL10 LH_2 Engine Main Control Valve	T-H-027	N.C. in Series with Engine Prevalve T-H-026 Fail closed - no propellant to engine. Fail open or leakage - in series with T-H-026.	 NI NI	None required for safety.	 NI NI
He RL10 LO_2 Engine Main Control Valve	T-H-028	N.C. in series with Engine Prevalve T-H-021 Fail closed - no propellant to engine. Fail open or leakage - in series with T-H-021.	 NI NI	None required for safety.	 NI NI
He LO_2 Topping Valve Control (Tank Isolation Valve)	T-H-029	N.C. Fail closed - no topping, potential launch scrub. Fail open or leakage before liftoff - topping would be stopped by ground valves - potential launch scrub. Fail open or leak after liftoff - in series with disconnect poppets. Topping line filled with propellant.	NI NI NI NI	None required for safety.	NI NI NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: N_2H_4 APS

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
N_2H_4 Fill & Drain, Manual	T-A-001	N. C. Seal leakage - Safety cap prevents leakage from escaping from system.	NI	None required	NI
N_2H_4 Thruster Shutoff: Module A Module B Module C Module D	T-A-003 T-A-004 T-A-005 T-A-006	N. O. Fails open in Orbiter bay; thruster series redundant valves prevent N_2H_4 from entering bay. Fails closed - closed is 'safed' condition. Internal leakage while in Orbiter bay; thruster series redundant valves prevent fluid escaping into bay.	NI NI NI	None required	NI NI NI
N_2H_4 Thruster Control Valves	T-A-007 through T-A-054	N. C. Fails open in Orbiter bay, series thruster shut-off valves prevent N_2H_4 from entering bay. Fails closed - Normal "in bay safed" condition. Internal leakage while in Orbiter bay; series thruster control shutoff valves are series redundant, in addition to module shutoff valves being shut.	NI NI NI	None required	NI NI NI
N_2H_4 Relief Valve No. 1 and No. 2	T-A-055 & T-A-056	N. C. Valve in series with T-A-056. N. C. Valve in series with T-A-055. No flow or leakage if either valve fails open. Failed closed normal "safed" condition.	NI NI	None required	NI NI
N_2H_4 Relief Valve No. 3	T-A-057	N. O. by APS arm safe not energized, in series with burst disc. Failed open or leakage normal safed condition. Failed closed - redundant system with valves No. 1 and No. 2	NI NI	None required	NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: O_2 Pressurization Vent

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
GO_2 Autogenous Press.	T-0-001	N.C. Fails open or leakage: allows GO_2 from main tank to back feed to main engine, and through the engine flow control valve and out O_2 injector into Orbiter Bay. Single failure would dump main tank GO_2 into Orbiter. Fails closed: Normal safety condition.	Catastrophic NI	Check valve has been added in series with autogenous pressurization valve to preclude possible back flow of propellants through a failed open pressurization valve.	NI NI
GO_2 Zero G Vent Valve No. 1 and No. 2	T-0-002 T-0-003	N.C. N.C. Fail closed - Normal safe condition. Fail open or leakage - Main tank allows GO_2 to be vented overboard through GO_2 vent line.	NI NI	None required	NI NI
GO_2 Zero G Vent Selector Valve	T-0-004	N.C. to zero thrust exhaust, open to overboard vent line. Failed closed; normal safed condition. Fail open or leakage: Vents GO_2 through zero thrust exhaust into Orbiter bay - but must also have Fail open of either No. 1 or No. 2 vent valve before venting can occur.	NI NI	None required	NI NI
LO_2 Zero-G Vent Mixer Motor	T-0-005	N.C. Failed closed: normal safe condition Failed open - (motor off): thermal efficiency less requiring more propellant vent to maintain pressure - but no safety problem with higher vent rates.	NI NI	None required	NI NI
LO_2 Fuel Cell Feed	T-0-006	N.C. Failed closed: normal safe condition Failed open or leakage: shut-off valve within fuel cell is backup for feed line failure to fuel cell.	NI NI	None required	NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: H_2 Pressurization/Vent

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
GH_2 Autogenous Press.	T-F-001	N.C. Fails open or leakage: allows GH_2 from main tank to back feed to main engine, through engine, and out H_2 injector and into Orbiter Bay. Single failure would dump main tank GH_2 into Orbiter.	Catastrophic	Check valve has been added in series with autogenous pressurization valve to preclude possible back flow of propellants through a failed open pressurization valve	NI
GO_2 Zero G Vent Valve No. 1 and No. 2	T-F-002 T-F-003	N.C. N.C. Failed closed: normal safe condition Failed open or leakage: allow main tank GH_2 to be vented overboard through GO_2 vent line.	 NI NI	None required	 NI NI
GH_2 Zero G Vent Selector Valve	T-F-004	N.C. to zero thrust exhaust, open to overboard vent line Failed closed: normal safe condition. Failed open or leakage: vent GH_2 through zero thrust exhaust into Orbiter bay, but must also have failed open either No. 1 or No. 2 vent valve before venting can occur.	 NI NI	None required	 NI NI
LH_2 Zero G Vent Mixer Motor	T-F-005	N.C. Failed closed: normal safe condition Failed open - (motor off): thermal efficiency less requiring more propellant vent to maintain pressure - but no safety problem with higher vent rates.	NI NI	None required	NI NI
LH_2 Fuel Cell Feed	T-F-006	N.C. Failed closed: normal safe condition Failed open or leakage: shutoff valve is backup for feed line failure to fuel cell.	NI NI	None required	NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: Deployment Adaptor

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He Supply System Primary Valve No. 1 and No. 2	D/A-H-001 D/A-H-002	N.C. N.C. Fail closed: Parallel valves, either one can fail. Fail open or leakage and tug attached: Tug helium fill valves T-H-001 and T-H-002 would also have to fail. Fail open or leakage and Tug deployed: adaptor disconnect poppet would also have to leak before losing adaptor He supply.	NI NI NI	None required	NI NI NI
He Supply Secondary No. 1 and No. 2	D/A-H-003 D/A-H-004	N.C. N.C. Fail closed: Parallel valves, either one can fail. Fail open or leakage: in series with: 006, 007, 008, and 009 valves for specific functions.	NI NI	None required	NI NI
He Bottle Fill Valve	D/A-H-005	N.C. Fail closed - would lose ability to fill or supply He for purges, tank pressurization and pilot operated valves. Failed open: in series with CK valve.	NI NI	None required	NI NI
He Ground Hold Fuel Panel Purge	D/A-H-006	N.C. Failed closed: Loss of He purge pressure to fuel panels (Tug/adapter and adapter/Orbiter). Panels would be filled with He purge from main fuel tank insulation purge exhaust. Failed open or leakage: No backup from exhausting adaptor He supply after Tug deployment. If He supply depleted, Tug tanks cannot be repressurized during reentry. Tug and PL must be jettisoned in space.	NI Operational Constraint	None required	NI NI

*NI = No impact on Space Shuttle Safety.

Table 4.7-4. Interface Safety Failure Mode Effects Analysis (Schematic I/T 74-010 Chg B) (Contd)

SUBSYSTEM: Deployment Adaptor

ITEM IDENT, FUNCTION & QUANTITY USED	SCHEM. REF. NO.	FAILURE MODE & EFFECT (IDENTIFY POTENTIAL HAZARD)	CRITICALITY*	CORRECTIVE ACTION (CONTAINED IN I/T 74-010 CHG C)	RESULTING CRIT.*
He Ground Hold Oxidizer Panel Purge	D/A-H-007	N. C. Same problems as D/A-H-006	Operational Constraint	None required	NI
He Flight GH_2 Vent Valve No. 1 and No. 2	D/A-H-008 D/A-H-009	N. C. Failed closed: parallel valves, either one can fail.	NI	None required	NI
		Failed open or leakage: either can fail open in series with GH_2 ground vent selector valve.	NI		NI
He Deployment Adaptor Vent No. 1 and No. 2	D/A-H-010 D/A-H-011	N. C. Valves in series		None required	
		Failed closed: Normal safe operation except in overpressure condition, in which case a parallel burst disc will protect system from catastrophic condition.	NI		NI
		Failed open: Either valve can fail open and not interfere with operations or system safety.	NI		NI

*NI = No impact on Space Shuttle Safety.

The reference fluid system schematic, I/T 74-010 CHG B, used for this FMEA has been updated (CHG C) to incorporate the indicated corrective action. As an aid in following Table 4.7-4, a copy of the outdated schematic has been included as Figure 4.6-6. The up-to-date fluid system schematic, which reflects implemented corrective action, is contained in Section 4 of Volume III.

The principal design features that were implemented to improve safety and reliability are:

a. The fuel and oxidizer fluid lines are routed through separate disconnect panels.

b. Each fluid interface panel is completely enclosed in a purge can. These purge cans are continuously purged with helium while the Tug contains propellants or propellant vapors and the Space Shuttle is within the earth's atmosphere.

c. Backup dump and vent valves have been incorporated into the interface to preclude the possibility that a failed open dump or vent valve on the Tug will result in implosion of a propellant tank or ingestion of atmospheric air. The backup valves are butterfly type that are biased to the open condition.

d. The oxygen topping line incorporates a self-sealing disconnect at both the Tug/adapter interface and the T-0 panel as backups to the topping line shutoff valve.

e. The helium fill lines incorporate self-sealing disconnects on both sides of the Tug-adapter interface. These disconnects provide backups to both the Tug helium supply shutoff valves and the adapter helium supply shutoff valves.

f. Helium purge components have been incorporated into the hydrogen fill/drain/dump line, hydrogen vent line, oxygen fill/drain/dump line, and the oxygen vent line. This purge precludes possible backflow of atmospheric oxygen and/or contaminants into these lines.

g. The helium supply system on the adapter incorporates dual redundant pressure regulation systems. Each regulator is backed up by a shutoff valve to guard against a failed-open regulator. The helium purge control valves are configured to provide at least fail-safe capability. In most cases, redundant control valves are used. The only instances where single control valves are employed are in the purge controls to the disconnect purge panels. The reason for these single control valves is that purging of the disconnect panels is required only when the redundant seals in a disconnect have failed.

h. Series valves have been incorporated on the helium fill line to preclude loss of helium if one of the valves should fail open. These valves also provide an overboard dump of the helium if required for an abort landing. Additionally, a burst disk is employed at the helium bottle manifold. If the dump system should fail

during an overpressurization condition, the helium pressure will be relieved through the burst disk.

In addition to the safety features that are a part of the MSFC baseline Tug design, the following modifications are recommended to enhance safety and reliability. These design features are contained in drawing I/T 74-010 chg C (contained in Section IV of Volume III).

a. Hydrazine storage bottles are provided with both overboard relief capability and crew-controlled overboard dump capability.

b. Tug helium pressurant supply bottles incorporate relief capability and crew-controlled overboard dump capability.

c. Helium pressure regulators are redundant, and each regulator is in series with a shutoff valve to protect against a failed open regulator.

d. All safety critical functions performed by the Tug have been provided with redundant control systems (propellant dump valves, propellant vent valves, tank pressurization regulators). Helium pressurant used in controlling valve positions is independently routed to each of the redundant valves. The control valves themselves are series redundant to preclude the chance that a failed open control valve will result in loss of control of any safety critical function.

e. Check valves are used between the autogenous pressurization control valves and the main engine. These check valves preclude backflow of propellants through the engine and into the payload bay if an autogenous pressurization control valve should fail open.

f. The helium pressure control valves that operate the main propellant isolation valves are separate from the control valves that operate the main engine valves. Consequently, a failed open control valve will not result in propellant flow through the main engine.

It is concluded that incorporation of the safety features described above for the Tug and the Tug interface equipment designs will result in a system that is wholly compatible with operations of the manned Space Shuttle. As indicated in the failure modes and effects analyses, all identified safety-critical single-point failures have been eliminated through design changes. Several single-point failures that can cause mission loss remain in the design. Most notable of these is the potential failure of the oxygen or hydrogen zero g vent systems. If either of these devices should fail while the Tug is in the Orbiter, the Orbiter crew can either 1) use the Orbiter RCS to accelerate the Orbiter to settle the propellants so that the ground/ascent vent system can be used, or 2) the Tug propellants can be dumped through the abort dump system. Failure of the zero g vent system will, however, cause mission loss and possibly loss of the Tug and

payload. It may be necessary to incorporate redundant zero g vent system in the Tug design to assure attainment of the 0.97 Tug reliability requirement.

4.7.3 SAFE RETRIEVAL OPERATIONS. The operations that pose the greatest hazards to the Orbiter/crew are considered to be those flight operations associated with retrieval of the Tug by the Orbiter. The Tug retrieval analysis contained in the Space Tug Systems Study (cryogenic) Vol II, Report No. CASD-NAS 73-033, was accordingly updated to reflect the changes to the Tug designs, including the result of the Tug Avionics Definition Study, to the present time. The Tug retrieval flight operations are summarized in Table 4.7-5. The updated Tug retrieval hazard analysis is contained in Table 4.7-6.

Each hazard in the hazard analysis is classified according to NASA Specification NHB 5300.4 (ID). The Hazard Severity column refers to the consequences of the hazard if it should occur. The Resulting Hazard Level column refers to the hazard level once the appropriate design or procedural controls have been implemented. The hazard levels and the corresponding hazard categories as defined in 5300.4 (ID) are:

a. Catastrophic (CA). No time or means are available for corrective action.

b. Critical (CR). Hazard may be counteracted by emergency action performed in a timely manner.

c. Controlled (CN). Hazard has been counteracted by appropriate design, safety devices, alarm/caution and warning devices or special automatic/manual procedures.

The Hazard Resolution/Control Actions column contains the designs, procedures, and operational constraints required to eliminate or control the hazard. The Constraints/Impacts column identifies organizations that are influenced by, and must implement, hazard controls.

As indicated in the hazard analysis, the safety features that have been designed into the Tug result in the capability to safely perform retrieval operations. The Tug deployment/retrieval mechanisms are designed to provide fail-operational/fail-safe capability, and the probability of multiple failures is considered to be small. Due to the nature of the Tug deployment/retrieval operation, however, it is conceivable that multiple failures of the deployment/retrieval system could, nevertheless, occur. To determine the feasibility of RMS/EVA use as a backup to the normal deployment/retrieval operations, an analysis was conducted to identify the RMS/EVA requirements that would have to be implemented to support Tug contingency deployment/retrieval operations. The results of this analysis are contained in Table 4.7-7.

Table 4.7-5. Tug/Orbiter Docking Sequence of Events

Event Sequence Initial Condition — Tug in Rendezvous Orbit — Orbiter Moved Within Docking Region	Tug Subsystems Active: DMS	GN&C	Guidance Update	Communication	Instrumentation	Electric Power	Power Dis. & Cont.	Main Engine	Main Engine Support	ACPS	Orbiter Interface
1. Dump main propellant residuals through abort dump system	↓	↓		↓	↓	↓	↓		↓	↓	↓
2. Safe main propellant lines	↓	↓		↓	↓	↓	↓		↓	↓	↓
3. Orbiter establish communication link with Tug	↓	↓		↓	↓	↓	↓		↓	↓	↓
4. Transfer Tug flight control to Orbiter	↓	↓		↓	↓	↓	↓		↓	↓	↓
5. Verify Tug safe for docking	↓	↓		↓	↓	↓	↓		↓	↓	↓
6. Orbiter ready cargo bay and manipulator	↓	↓		↓	↓	↓	↓		↓	↓	↓
7. Command Tug to preferred docking attitude	↓	↓		↓	↓	↓	↓		↓	↓	↓
8. Orbiter maneuver to final docking station	↓	↓		↓	↓	↓	↓		↓	↓	↓
9. Inhibit Tug APS thrusters	↓	↓		↓	↓	↓	↓		↓	↓	↓
10. Attach manipulator to Tug	↓	↓		↓	↓	↓	↓		↓		↓
11. Retract Tug to cargo bay	↓	↓		↓	↓	↓	↓		↓		↓
12. Mate and latch Tug to adapter	↓	↓		↓	↓	↓	↓		↓		↓
13. Connect umbilicals	↓	↓		↓	↓	↓	↓		↓		↓
14. Rotate into cargo bay and latch forward structural support	↓	↓		↓	↓	↓	↓		↓		↓
15. Shut down GN&C and communication	↓	↓		↓	↓	↓	↓		↓		↓
16. Switch to Orbiter power, shut down fuel cell	↓				↓	↓	↓		↓		↓
17. Purge LH_2 tank with helium	↓				↓		↓		↓		↓
18. Pressurize main propellant tanks and lines with helium	↓				↓		↓		↓		↓

Table 4.7-6. Tug Retrieval Hazards Analysis

Event No.	Hazard	Hazard Severity	Hazard Resolution/ Control Actions	Con-straints/ Impacts	Resulting Hazard Level
0	Tug enters collision course with Orbiter at Tug return due to Tug guidance navigation error or human error.	CA (Tug) CA (Orbiter)	Tug return profile places Tug in an orbit 10 n. mi. above that of Orbiter. Tug has dual communications links to ensure safe remote Tug engine shutdown capability.	Design/ Orbiter/ Operations	CN (Tug) CN (Orbiter)
1	Failure to establish communication can result in: (1) inability to crew to obtain control of safety critical functions (2) inability of crew to status Tug safety critical	CA (Tug) CN (Orbiter)	Tug design incorporates dual redundant communication links, either of which will allow the Orbiter crew to status the Tug and to obtain control of safety critical functions.	Design	CN (Tug) CN (Orbiter)
2	Inability of Orbiter crew to obtain control of Tug flight control system will result in inability to command Tug to preferred docking attitude and inability to override Tug unprogrammed motion.	CA (Tug) CA (Orbiter)	Tug design incorporates dual data management systems, dodecahedron IMUs, fail operational/fail safe ACPS and dual communication links. This design provides a backup for all safety critical command and control functions.	Design	CN (Tug) CN (Orbiter)
3	Inadvertent activation of main propulsion system while Tug is in vicinity of Orbiter or in payload bay.	CA (Tug) CA (Orbiter)	Tank outlet valves, in series with the main engine valves, are closed via rf link. Main engine valves are then sequentially opened to vent the main propellant lines.	Design/ Operations	CN (Tug) CN (Orbiter)
4	Status of unexpended pyrotechnics, hazardous payloads and safety critical components.	CA (Tug) CA (Orbiter)	Dual redundant communications used. All safety critical components statused prior to approach to Tug. Adequacy of ACPS propellant quantity verified.	Design	CN (Tug) CN (Orbiter)
6	Contamination of Orbiter due to Tug dumped ACPS propellants.	CR	ACPS propellants are not normally dumped. (ACPS propellant dump may be accomplished during an aborted flight)	Design/ Operations	CN
7	Tug/Orbiter collision (due to failed Tug ACPS, failed Tug data management, failed Tug guidance).	CA (Tug) CA (Orbiter)	Tug ACPS incorporates dual redundant astrionics system and propellant isolation valves that are controlled by the Orbiter crew via rf link. ACPS is fail operational/fail safe.	Design, Operations	CN (Tug) CN (Orbiter)

Table 4.7-6. Tug Retrieval Hazards Analysis (Contd)

Event No.	Hazard	Hazard Severity	Hazard Resolution/ Control Actions	Con-straints/ Impacts	Resulting Hazard Level
7	Tug perturbation due to plume impingement from Orbiter RCS thruster could cause rotation of Tug into Orbiter during critical retrieval maneuver.	CA (Tug) CA (Orbiter)	Tug ACPS system will remain activated until just prior to manipulator engagement. Tug ACPS will have the capability of holding the Tug in a steady attitude.	Design/ Orbiter/ Operations	CN (Tug) CN (Orbiter)
7	Tug/Orbiter collision. Due to energy imparted to Tug from propellant venting.	CR	All the Tug vents are nonpropulsive. Any minor perturbations due to venting will be cancelled by action of ACPS.	Design/ Orbiter/ Operations	CN
8	If ACPS is not inhibited until after manipulator engagement, Orbiter and Tug ACPS may begin to "fight" each other.	CR (Tug) CR (Orbiter)	Tug ACPS is inhibited just prior to engagement by Orbiter manipulator. Dual communication links are used to assure receipt of ACPS inhibit command.	Design, Orbiter	CN (Tug) CN (Orbiter)
9	Puncture of a main propellant tank with the manipulator arm can cause loss of Tug. Puncture of a high pressure bottle can cause damage to the Orbiter.	CA (Tug) CA (Orbiter)	Tug will incorporate a reinforced buffer shield around the manipulator attachment area. The Tug bottles are located in the protected intertank area.	Design/ Operations Orbiter	CN (Tug) CN (Orbiter)
10	Damage to manipulator and/or Orbiter due to use of manipulator to accelerate Tug at excessive rates.	CA (Tug) CA (Orbiter)	Retraction of Tug into payload bay must be done very slowly. It may be necessary to employ a rate limiter on the manipulator.	Orbiter, Operations	OPEN (Requires Orbiter action)
11	Inability to engage Tug latches/ umbilicals will result in a potentially hazardous situation as there will be no monitoring and override control of Tug safety critical functions.	CA (Tug) CA (Orbiter)	Redundant electrical power sources are used to operate Tug/Adapter latches. Additionally, latch and umbilcal engagement capability is available via RMS or EVA if normal latching is unsuccessful.	Design/ Orbiter	CN (Tug) CN (Orbiter)
11	High voltage arcing/burning at electrical disconnects could preclude reconnection.	CA (Tug) CN (Orbiter)	No high voltage will be present at Tug/Orbiter umbilicals during docking.	Design	CN (Tug) CN (Orbiter)
13	Failure of retraction mechanism to rotate Tug/adapter to stowed position resulting in inability to close payload bay doors.	CA (Tug) CA (Orbiter)	Retraction mechanism command and control is dual redundant. Both Tug and adapter can also be remotely or manually disengaged from Orbiter via RMS or EVA.	Design, Operations	CA (Tug) CN

Table 4.7-6. Tug Retrieval Hazards Analysis (Contd)

Event No.	Hazard	Hazard Severity	Hazard Resolution Control Actions	Constraints/ Impacts	Resulting Hazard Level
13	Tug/payload instability due to failure of forward attachment link to engage.	CA (Tug) CA (Orbiter)	Forward attachment link can be engaged via RMS or EVA. If this is unsuccessful, it may be necessary to jettison the Tug/paylopd prior to Orbiter return.	Design/ Orbiter	CN (Tug) CN (Orbiter)
14 15	Loss of Tug power due to inability to shift to Orbiter power will result in loss of capability to perform safety critical monitoring and override functions.	CA (Tug) CA (Orbiter)	Power supply paths between Orbiter and Tug are expected to be redundant. If both paths fail, it may be necessary to abandon Tug in orbit.	Design, Operations, Orbiter	CA (Tug) CN (Orbiter)
16	Failure to achieve dump of residual main propellants will not, in itself, present a hazard to the Orbiter or Tug. It is, however, considered to be good safety practice to dump the residuals and to use the abort helium to purge the hydrogen tank.	CR (Orbiter)	Series/parallel dump valves are used to assure dump capability for both propellant tanks. This arrangement also assures that dump lines can be reclosed prior to purging and entry operations.	Design, Orbiter	CN (Tug) CN (Orbiter)
17 18	Main propellant tanks/lines that are emptied must be repressurized prior to entry to preclude crushing.	CA (Tug) CA (Orbiter)	The abort helium system is used to purge the hydrogen tank and lines. Both hydrogen and oxygen tanks and lines are then pressurized with helium to approximately 20 psi (14061 kg/m^2).	Design, Operations	CN (Tug) CN (Orbiter)

The contingency analysis indicates that use of the RMS as an emergency backup device will enhance the overall safety and reliability of the Tug operations. For the RMS to be fully effective, however, the RMS must incorporate the capability to provide on-orbit end effector exchange and stowage capability. This will allow the RMS to be used in accomplishing wrenching or grasping functions during contingency operations.

A Space Shuttle program Level II Change Request was accordingly generated to request increased capability and flexibility of the RMS terminal device/end effector. Incorporation of this change will result in increased capability of the RMS to be used in recovering from contingency situations. Details of the RMS requirements change request are contained in Level II Change Request 005 (reference Section 5 Volume III).

4.7.4 SIGNIFICANT ISSUES SUMMARY. The safety and reliability analyses have indicated that the interface designs are in conformance with all significant Space Tug

Table 4.7-7. RMS/EVA Requirements to Support Tug Deployment/Retrieval Contingency Ops

Deployment Sequence	Deployment/Retrieval Function Sequence	Retrieval Sequence	Mechanism Involved and Design Features	Contingency Ops Support Requirements: RMS	EVA	Remarks
1	Undock RMS and move clear/stow RMS	10	Orbiter provided function.			
2	Retract/reconnect	9	Fuel and oxidizer disconnect panel retraction actuator. Redundant motor elec. screw actuator. Deployment adapter rotation (step 4/7) will disconnect/connect lines.	X	X	End effector adapter or EVA tool to apply required torque to screw drive mechanism.
3	Unlatch/latch forward Z fittings	8	Forward Z fitting and guide. Redundant motor elec. actuator.	X	X	Assume capability for end effector adapter or EVA tool to apply required torque to drive mechanism. (Orbiter provided, assumed compatible with RMS/EVA tool.)
4	Rotate payload out of/into cargo bay Disengage/engage fwd and aft Y fittings	7	Pivot actuators Dual redundant elec. motor actuator drive.	X	X	End effector adapter to pull pin and permit redundant actuator to accomplish rotation. EVA tool for same use. Also end effector EVA

Table 4.7-7. RMS/EVA Requirements to Support Tug Deployment/Retrieval Contingency Ops (Contd)

Deployment Sequence	Deployment/Retrieval Function Sequence	Retrieval Sequence	Mechanism Involved and Design Features	Contingency Ops Support Requirements: RMS	EVA	Remarks
			Tandem motors on each drive. Forward and aft Y fittings and guides.			tool to apply required torque.
5	Attach RMS	6	Orbiter provided RMS with end effectors. Grasping point(s) on Tug compatible with end effectors.		X	From this point to deployment step 10, RMS is attached to Tug and is not available for contingency use. EVA is only option. (Also applies from retrieval step 2 to this step in retrieval sequence.) EVA to assist with RMS attach/release function.
6	Retract/reconnect electrical umbilical panels	5	Electrical umbilical panel and panel retraction actuator. Redundant motor elec. screw actuator. Tug withdrawal from/insertion into adapter will disconnect/reconnect elec. lines.			Rely upon Tug motion out of/into adapter to accomplish disconnect/reconnect of elec. lines

Table 4.7-7. RMS/EVA Requirements to Support Tug Deployment/Retrieval Contingency Ops (Contd)

Deployment Sequence	Deployment/Retrieval Function Sequence	Retrieval Sequence	Mechanism Involved and Design Features	Contingency Ops Support Requirements: RMS	EVA	Remarks
7	Unlatch/relatch Tug-adapter latches. Disengage/reengage shear pins	4	Tug-adapter latches. Over center link with redundant motor elec. screw actuator. Adjoining latches are coupled for redundancy on unlatching. Actuator provides sufficient force to disengage/reengage alignment shear pins.		X	Failure of one latch will not require EVA for deployment. EVA tool to apply required torque to actuator drive in event of multiple failure.
8	Deploy/retrieve using RMS	3	Orbiter provided RMS.			
9	Extend/retract engine nozzle final pre-deployment C/O, preretrieval safety check.	1	Tug engine supplied actuator subsystem			Tug in deployed position and held by RMS. Nozzle actuation, C/O, safety check accomplished using Tug-Orbiter RF link. Tug provide means to jettison nozzle extension if it can't be retracted.
10	Release/attach RMS	2	Orbiter provided RMS with end effectors. Grasping point(s) on Tug compatible with end effectors		X	EVA to assist with release/attach function. NOTE: Tug engine nozzle is retracted before RMS attach to Tug during retrieval sequence.

safety requirements except those for horizontal drain of the main propellants. The reliability analysis, based on conservative reliability estimates for the dump valves, indicate that the chance of an abort dump failure is extremely remote. If, however, a dump failure of the hydrogen tank should occur, the Orbiter can still land safely. The horizontal vent valve will allow safe venting of the hydrogen, and the only consequence would be a possible turnaround delay due to having to wait for hydrogen boiloff. If failure of the redundant dump valves on the oxygen tank should result in failure to dump the oxygen during abort, the oxygen propellant tank will structurally fail at landing. Horizontal drain capability in this case will not, of course, preclude this consequence. If an abort dump pressurization failure should occur, at least 65 percent of the hydrogen and 80 percent of the oxygen will be dumped. The Orbiter can land safely with the residual propellants aboard, and the propellant levels will be below the vent outlets. The propellants can thus be safely boiled off. The only negative consequence in this case, as in the case of a hydrogen dump failure, is that a turnaround time delay may occur.

The conclusion drawn from the analysis is that the additional cost, weight, and complexity associated with implementation of horizontal drain capability is not justified.

The caution and warning logic described in Section 4.8 provides a systematic and disciplined approach to identifying the safety critical data that should be displayed to flight and ground crews. The specific cautions and warnings identified are based on Tug designs and operations concepts to date. It should be recognized, however, that modification to Tug designs and/or operations concepts can result in a different set of caution and warning parameters.

The Tug hazard analyses and failure modes and effects analyses should be continually updated to reflect the changes associated with the evolving Tug program, and the results of these analyses should be used in assessing the adequacy of the caution and warning system.

A conflict in the safety requirements contained in different segments of MSFC 68M00039 can have a significant influence on the Tug and the Tug interface designs. The potential conflicts in the safety requirements contained in the Tug requirements documents deal with the level of fault tolerance to be designed into the Tug. MSFC 68M00039-1, Appendix II, requires that all mission-critical functions be designed to fail operational/all others fail safe. The requirement in the MSFC 68M00039-1 document requires that no single failure will result in hazards which jeopardize the safety of the Orbiter or crew.

If the Tug mission critical subsystems are designed to fail operational, the equipment redundancy necessary to attain this requirement can be extensive. For example: if the Tug arm/safe switch were made fail-operational, a series/parallel network of four arm/safe switches would be required (to allow continued operational capability if any switch should fail in the open or closed mode). Individual monitoring and control of each of these arm/safe switches would significantly increase the complexity of the Orbiter/Tug interface.

In contrast, the requirement that no single failure will result in a hazard that jeopardizes the flight or ground crews can be implemented with relative ease. In the arm/safe switch example, only a single arm/safe switch is required for fail-safe operation (i.e., it would take a failure of both the arm/safe switch and an inadvertent signal for the safety of the flight or ground crews to be compromised). This, of course, greatly simplifies the Tug design and the associated interfaces. It is therefore recommended that the criterion be "no single failure shall result in a hazard which jeopardizes the flight or ground crews." Any exceptions to this requirement, such as a fail-operate/fail-safe deployment/retrieval system and fail-operate/fail-safe ACPS should be specifically identified in the requirements document.

SECTION 5

SENSITIVITY ANALYSES

Incorporation of specific Tug interface needs in the Orbiter before Tug development requires a complete understanding of what effect Tug operations and systems changes will have on interface requirements. Tug changes that result in critical Orbiter interface requirement impacts were identified in this task to permit possible desensitizing of applicable Tug/Shuttle interface accommodations.

Detailed Tug/Shuttle interface requirements were obtained in Task 2 (Section 4) for the Space Tug. The sensitivity analysis determined impacts to these interface requirements caused by major changes in Tug operational and design characteristics.

Sensitivity investigations were made to consider variations in the following areas:

Orbiter Versus Ground Control and Monitoring — Four options to the baseline system were investigated for reducing Tug ground control and status monitoring: 1) increased Orbiter crew monitor and control capability, 2) high Tug autonomy for onboard control, 3) expanded use of peripheral avionics equipment on the Tug deployment adapter, and 4) use of Tug-supplied rather than Orbiter-supplied Tug support equipment.

Tug Self-Checkout Capability — Implementation of higher and lower levels of onboard checkout capability (with respect to the baseline Tug) were examined.

Secure Communications — Department of Defense may incorporate communications security (COMSEC) units on Tug, its payload, and on Orbiter. The physical, functional, and operational interface impact was assessed.

Fluid Services — Major sensitivities in Tug design and operations were investigated for storable propellants, load dump variations, N_2 pressurization/purge, cryogenic ACPS, and off-pad loading.

Tug Payload Services — Service sensitivities due to two types of Tug changes were considered: changes affecting 1) the number and type of payload/Orbiter services that can be routed through the Tug, and 2) payload services provided by the Tug.

Alternative Abort Modes — Parametric data was generated to provide rapid effects evaluation for abort sensitive Tug/Orbiter interfaces; i.e., LH_2 and LO_2 dump line diameters.

Tug Length — The possible need to deploy very long spacecraft or perform high-energy retrieval missions may result in Tug length variations from 20 to 35 feet (6.1 to 10.7

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meters). Interface effects due to these length changes include structural attachment and pivot locations, reaction magnitudes, and Tug center of gravity position.

Description of investigation approach and results/recommendations for each of these seven sensitivities is contained in Sections 5.1 through 5.7. A summary of the combined results/recommendations and their influence on interface analyses results obtained in Task 2 (Section 4) is presented in Section 5.8.

5.1 ORBITER VERSUS GROUND CONTROL AND MONITORING

The avionic analyses conducted in study Task 2 started from a baseline operating concept (supplied by NASA) that specified to what extent Orbiter performed Tug control and monitor operations (with respect to those allocated to ground functions). The Orbiter Versus Ground Control and Monitoring sensitivity was performed to assess the interface requirements impact (benefit versus costs) due to implementation of four variations of the baseline control and monitor concept.

Three of the four alternative Tug control and monitoring concepts involve allocation of control philosophy with respect to the ground, Orbiter, or Tug vehicle. These are: 1) increased ground control/decreased Orbiter control, 2) increased Orbiter crew monitor and control capability, and 3) increased Tug autonomy/decreased Orbiter/ground control.

The fourth alternative is somewhat different from the other three because the baseline Orbiter/Tug/ground control and monitor operational allocations are the same but alternative means of providing the control and monitor equipment and software employs Orbiter-supplied payload support equipment is evaluated against the use of Tug supplied-control and monitor equipment at the payload specialist station and a Tug data processor capability located in the Orbiter cargo bay on the Tug deployment adapter.

These four alternative concepts (Figure 5.1-1) were evaluated with respect to: safety, interface complexity items including equipment required, physical and software interfaces, operational complexity, crew effectivity, weight, and cost.

Details of these configurations, associated sensitivity analyses, and results are discussed in the following sections.

5.1.1 <u>MONITOR AND CONTROL GROUND RULES.</u> Before initiating this task it was necessary that common ground rules be established for certain Orbiter safety, reliability, and operational procedures. These are:

a. Tug shall be fail-safe (not necessarily fail-safe/fail-operational).

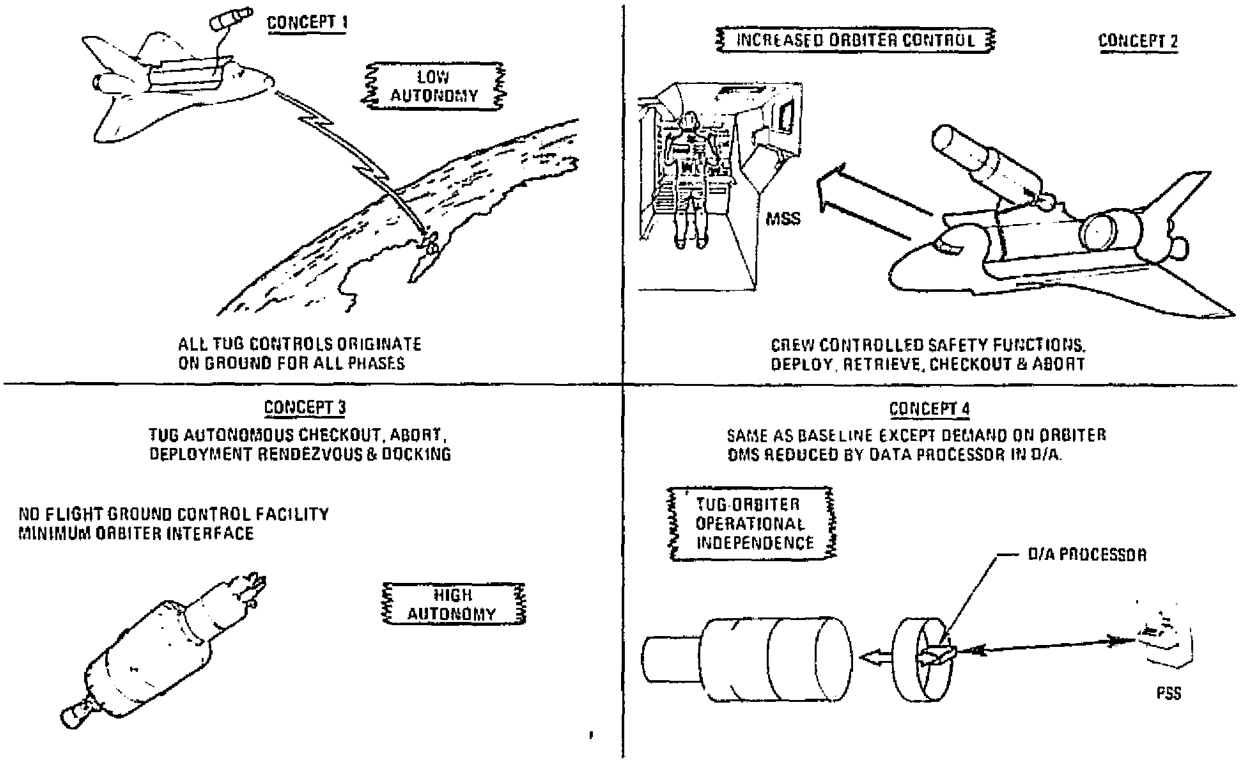

Figure 5.1-1. Alternative Tug/Orbiter/Ground Control and Monitor Concepts

b. Safety functions shall not require Orbiter support during prelaunch operations.

c. Safety functions require backups by data link or hardwire.

d. Safety functions (abort control) shall not be dependent on RF links to/from ground.

e. Safety monitors will be telemetered to ground.

f. Reliability of all Orbiter functions is equal to one (by definition).

g. Tug will telemeter deployment adapter (D/A) monitors when in cargo bay.

5.1.2 <u>CONCEPT 1, MINIMUM ORBITER MONITOR AND CONTROL/MAXIMUM GROUND CONTROL.</u> Concept 1 was investigated to determine if Orbiter onboard control of Tug and Tug associated interfaces can be minimized by designing Tug such that the majority of its nonautonomous control and monitoring operations are performed by a ground flight control operation. The interface control and monitoring paths and the functional operations allocated among the Tug, Orbiter, and ground for this concept are shown in Tables 5.1-1 and 5.1-2 respectively. As indicated in these tables, this system would rely on Tug/ground and Tug/Orbiter/ground RF communication links for

Table 5.1-1. Tug Interface Paths (Concept 1 - Increased Ground Control)

Phase	Function	Backup Requirement*	Primary Path Up	Primary Path Down	Backup Path Up	Backup Path Down	Comments
Prelaunch	Safety Critical	S	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	Operational B/U via gnd RF/PSP link
	Operations	O	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	
	Power	S	Orb Sta 695 Ded Fuel Cell	-	Orb Sta 695 Main Bus	-	Deployment adapter power through Orb Sta 1307
Ascent	Safety Critical	S	PSP - GPC No. 1	C&W to MSS TLM - PSP	PSP - GPC No. 2	TLM - PSP No. 2	
	Abort	S	PSP to DMS	TLM via PSP	PSP to CIU & D A IU	PSP No. 2	Operational B/U via gnd RF/PSP
	Ground Comm	C	PSP/ORB	PSP/ORB	PSP 2/ORB	PSP 2/ORB	
	Power	S	Tug Fuel Cells (2)	-	Orb Sta 695	-	Deployment adapter power through Orb Sta 1307
On-Orbit Attached	Safety Critical	Same as ascent					
	Abort						
	Ground Comm						
	Power						
	Operations	O	GND to ORB/PSP	PSP/ORB to GND	GND to ORB PSP 2	PSP 2 ORB to GND	
On-Orbit Detached	Safety Critical	S	PI	PI	PI 2	PI 2	Arm Safing & loiter RF commands
	Operations	R	Gnd Net	Gnd Net	Gnd Net 2	Gnd Net 2	

*S = Safety
R = Mission Reliability
C = See comments
O = Operational Convenience

Table 5.1-2. Concept 1, Increased Ground Control Operations Allocations

	Control/Monitor		
	Ground	Orbiter	Tug
CONTROLS			
Safety Critical	B/U	X	
Communications	X		
Vents			X
Purges			X
Update G&N	X		
Umbilical Mechanisms	X		
Forward Latches		X	
D/A Rotation	X		
D/A Latches	X		
Fuel Cell Activation	X		
Power Changeover	X		
Predeployment Checkout	X		
ACS Arming	X	B/U	
Loiter	X	B/U	
Main Propulsion Arming	X	B/U	
Mission Sequence Start	X	B/U	
Main Propulsion Safing	B/U	X	
Propellant Dump	X		
Precapture Checkout	X		
ACS Safing	B/U	X	
Fuel Cell Deactivation	X		
Abort	B/U	X	
MONITORS			
C&W	B/U	X	
Tug Status	X	B/U	

all operational command, control, and data monitoring operations. During ascent/ descent, before Tug deployment, and after Tug rendezvous and capture by the Orbiter, this communication link must interface with and employ the Orbiter's RF communications system to communicate with the Tug ground control facility/system.

Because this concept is dependent on adequate ground coverage during launch, descent and Tug/Orbiter on-orbit operations (160 n. mi., 300 km), a ground coverage evaluation was performed for NASA STDN, NASA TDRS, and DOD SCF communication networks. Typical coverage from STDN and TDRSS is shown in Figure 5.1-2. Although precise coverage can be determined only for a specific trajectory, this figure shows that there are regions of assured 100% coverage, others of less than 100%, and even some excluded regions of zero coverage. Four STDN ground stations are shown. These provide full tracking and data services for direct communication or communication via a TDRS. The longest interval between STDN stations is between Madrid and Orroral. If the radius bisecting the great circle between these stations is extended, an altitude is reached (14,888 n. mi., 27,600 km) at which both stations are visible. The peak at approximately 76 degrees longitude represents a region of no STDN coverage below an altitude of 14,888 n. mi. (27,600 km). There are similar regions between each pair of stations. However, the no coverage altitude is very much lower since the stations are closer together. At approximately 6400 n. mi. (11,860 km), the maximum altitude for TDRSS use is shown with three small regions of excluded coverage.

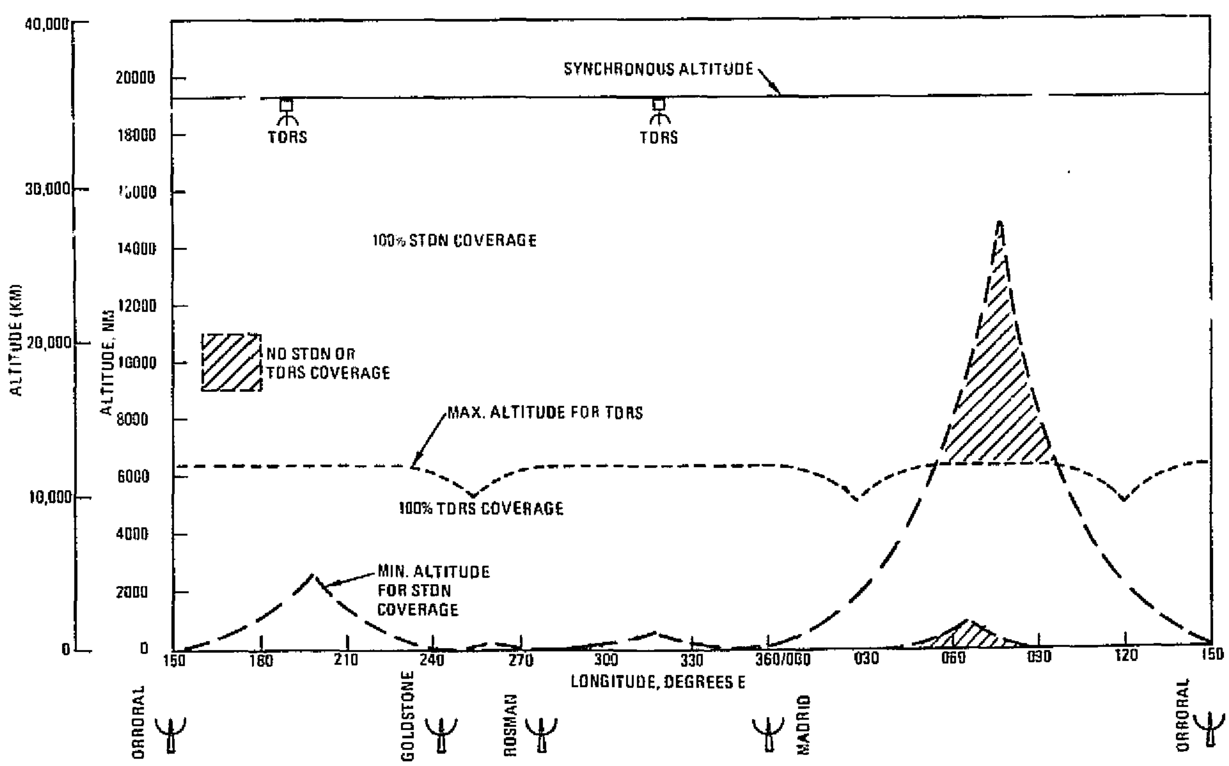

Figure 5.1-2. Tug-TDRS/STDN Ground Coverage

During Tug/Orbiter operations through the Tug's first engine burn, the Tug and Orbiter are at an altitude of about 160 n. mi. (300 km). At this altitude, the ground station radius-of-visibility is approximately 900 n. mi. (1667 km). Figures 5. 1-3 and 5. 1-4 illustrate the areas of coverage for the STDN and SCF stations. It is apparent that the chances of Orbiter/Tug operations and Tug first burn occurring over an existing ground station are slim unless the trajectory is severely constrainted. Thus, the TDRS system and/or a network of instrumentation ships or mobile ground stations is required to make Concept 1 a viable Tug control and monitor candidate. In any event, since ground coverage during all Tug/Orbiter mission phases cannot be assumed, it is recommended that safety functions and abort control responsibility be allocated to the Orbiter and its crew for all Tug/Orbiter concepts.

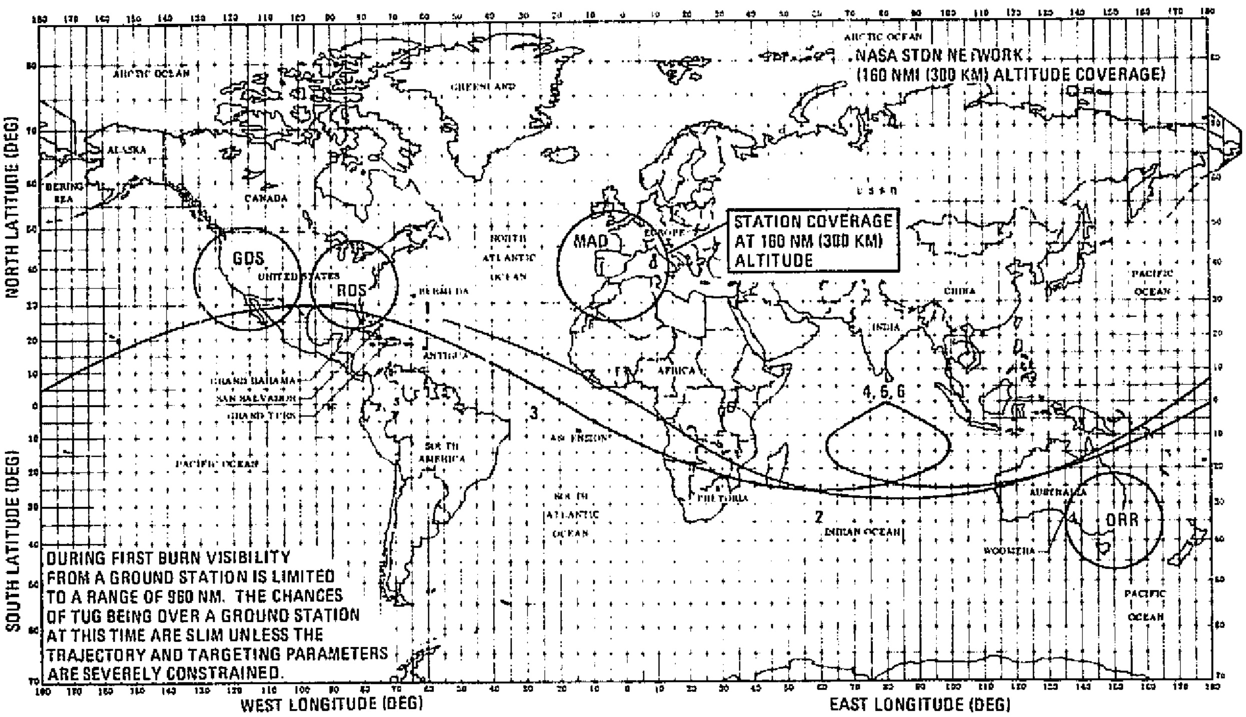

Figure 5. 1-3. Ground Track for Reusable Tug Reference Geosynchronous Mission NASA STDN Network

5.1.3 CONCEPT 2, INCREASED CREW MONITOR AND CONTROL. Concept 2 was evaluated to determine if increased Orbiter support capability in excess of the Orbiter crew-controlled baseline Tug functions for critical safety items, Tug deployment, retrieval, retrieval "safed" interrogation, and abort could significantly reduce ground control requirements. Also, additional Orbiter requirements (in relation to baseline Tug) and corresponding impacts on the Orbiter data management system, software, MSS/PSS equipment allocation, Orbiter crew effectivity, power requirements, data transmission requirements, etc. were determined. These operations would include Tug checkout and greater RF control of the Tug while in the deployed mode.

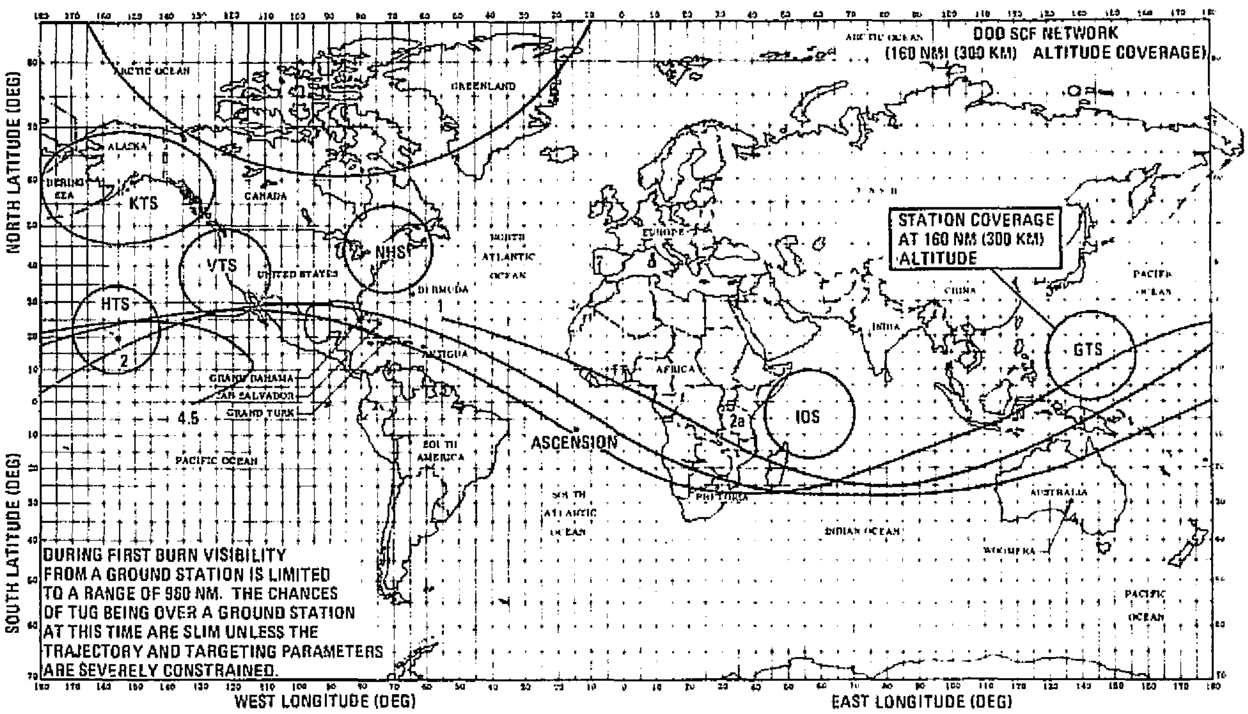

Figure 5.1-4. Reference DOD Geosynchronous Mission Ground Trace

Tables 5.1-3 and 5.1-4 show the Tug/Orbiter/ground interface paths and the operations allocations, respectfully, for this configuration.

5.1.4 CONCEPT 3, HIGH AUTONOMY TUG. A reduction in Tug-to-Orbiter/ground interface requirements will result from a Tug data management system design that provides a hardware and software capability to perform complete Tug health assessment and to execute abort, deployment, or rendezvous and docking operations autonomously. No ground flight control facility would be required and only a limited degree of Orbiter support capability would be required. The basic Tug/Orbiter/ground interface and operational requirements for this concept were developed using, but not significantly adding to, present Orbiter payload support capabilities. Additional requirements for the Tug, its support adapter, and communications interfaces were also identified and costed. Tables 5.1-5 and 5.1-6 describe the concept, where only "red" or "green" status indications for each major Orbiter/Tug flight operation are needed.

5.1.5 CONCEPT 4, EXPANDED SUPPORT ADAPTER AVIONICS. An analysis was performed to evaluate the use of a separate and unique Tug support station (TSS) that communicates with a data processor located on the Tug support adapter to effect Tug operational (nonsafety) control and monitor functions. This technique, shown schematically in Figure 5.1-5 permits the Orbiter crew to maintain necessary control over Tug with minimized use of Orbiter GPC and GPC software support system.

Table 5.1-3. Tug Interface Paths (Concept 2, Increased Orbiter Control)

Phase	Function	Backup Requirement*	Primary Path		Backup Path		Comments
			Up	Down	Up	Down	
Prelaunch	Safety Critical	S	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	Operational B/U via gnd RF/PSP link
	Operations	O	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	TLM via Orbiter is alternative (RF or umbilical)
	Power	S	Orb Sta 695 Ded Fuel Cell	-	Orb Sta 695 Main Bus	-	Deployment adapter power through Orb Sta 1307
Ascent	Safety Critical	S	PSP - GPC No. 1	C&W to MSS TLM - PSP	PSP - GPC No. 2	TLM - PSP No. 2	
	Abort	S	PSP to DMS	TLM via PSP	PSP to CIU & D/A IU	PSP No. 2	Operational B/U via gnd RF/PSP
	Ground Comm	C	PSP/ORB	PSP/ORB	PSP 2/ORB	PSP 2/ORB	
	Power	S	Tug Fuel Cells (2)	-	Orb Sta 695	-	Deployment adapter power through Orb Sta 1307
On-Orbit Attached	Safety Critical		Same as ascent				Includes significant prelaunch checkout, TLM monitoring, data reduction trend monitoring.
	Abort						
	Ground Comm						
	Power						
	Operations	O	PSP - GPC	PSP to GPS	PSP 2 to GPC	PSP 2 to GPC	
On-Orbit Detached	Safety Critical	S	PI	PI	PI 2	PI 2	Arm/Safing & loiter RF commands
	Operations	R	PI	PI	PI 2	PI 2	No ground operations capability. Orbiter performs precapture Tug safing, control, & checkout.

*S = Safety　　C = See comments
R = Mission Reliability　　O = Operational Convenience

Table 5.1-4. Concept 2, Increased Orbiter Interface Operations Allocations

	Controller/Monitor		
	Ground	Orbiter	Tug
CONTROLS			
Safety Critical		X	
Communications		X	
Vents			X
Purges			X
Update G&N		X	
Umbilical Mechanisms		X	
Forward Latches		X	
D/A Rotation		X	
D/A Latches		X	
Fuel Cell Activation		X	
Power Changeover		X	
Predeployment Checkout		X	
ACS Arming	B/U	X	
Loiter	B/U	X	
Main Propulsion Arming	B/U	X	
Mission Sequence Start	B/U	X	
Main Propulsion Safing	B/U	X	
Propellant Dump		X	
Precapture Checkout		X	
ACS Safing	B/U	X	
Fuel Cell Deactivation		X	
Abort		X	
MONITORS			
C&W	B/U	X	
Tug Status	B/U	X	

Table 5.1-5. Tug Interface Paths (Concept 3, High Autonomy Tug)

Phase	Function	Backup Requirement*	Primary Path Up	Primary Path Down	Backup Path Up	Backup Path Down	Comments
Prelaunch	Safety Critical	S	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	Operational B/U via gnd RF/PSP link
	Operations	O	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	TLM via Orbiter is alternative (RF or umbilical)
	Power	S	Orb Sta 695 Ded Fuel Cell	-	Orb Sta 695 Main Bus	-	Deployment adapter power through Orb Sta 1307
Ascent	Safety Critical	S	PSP - GPC No. 1	C&W to MSS TLM - PSP	PSP - GPC No. 2	TLM - PSP No. 2	
	Abort	S	PSP to DMS	TLM via PSP	PSP to CIU & D/A IU	PSP No. 2	Operational B/U via gnd RF/PSP
	Ground Comm	C	PSP	PSP	PSP 2	PSP 2	
	Power	S	Tug Fuel	-	Orb Sta 695	-	Deployment adapter power through Orb Sta 1307
On-Orbit Attached	Safety Critical	Same as ascent					Orbiter monitor results of Tug control requests (red/green light approach)
	Abort						
	Ground Comm						
	Power						
	Operations	O	PSP - GPC	PSP to GPS	PSP 2 GPC	PSP 2 GPC	
On-Orbit Detached	Safety Critical	S	PI	PI	PI 2	PI 2	Arm/Safing & loiter RF commands
	Operations	R	ORB/PI	ORB/PI	Gnd Net 2	Gnd Net 2	

*S = Safety
R = Mission Reliability
C = See comments
O = Operational Convenience

Table 5.1-6. Concept 3, High Autonomy Tug Interface Allocations

	Controller/Monitor		
	Ground	Orbiter	Tug
CONTROLS			
Safety Critical		X	
Communications			X
Vents			X
Purges			X
Update G&N			X
Umbilical Mechanisms		X	
Forward Latches		X	
D/A Rotation		X	
D/A Latches		X	
Fuel Cell Activation			X
Power Changeover		X	
Predeployment Checkout			X
ACS Arming		X	
Loiter		X	
Main Propulsion Arming		X	
Mission Sequence Start			X
Main Propulsion Safing		X	
Propellant Dump			X
Precapture Checkout			X
ACS Safing		X	
Fuel Cell Deactivation		X	
Abort		X	
MONITORS			
C&W	B/U - Deployed	X - Deployed	X - Attached
Tug Status		B/U	X

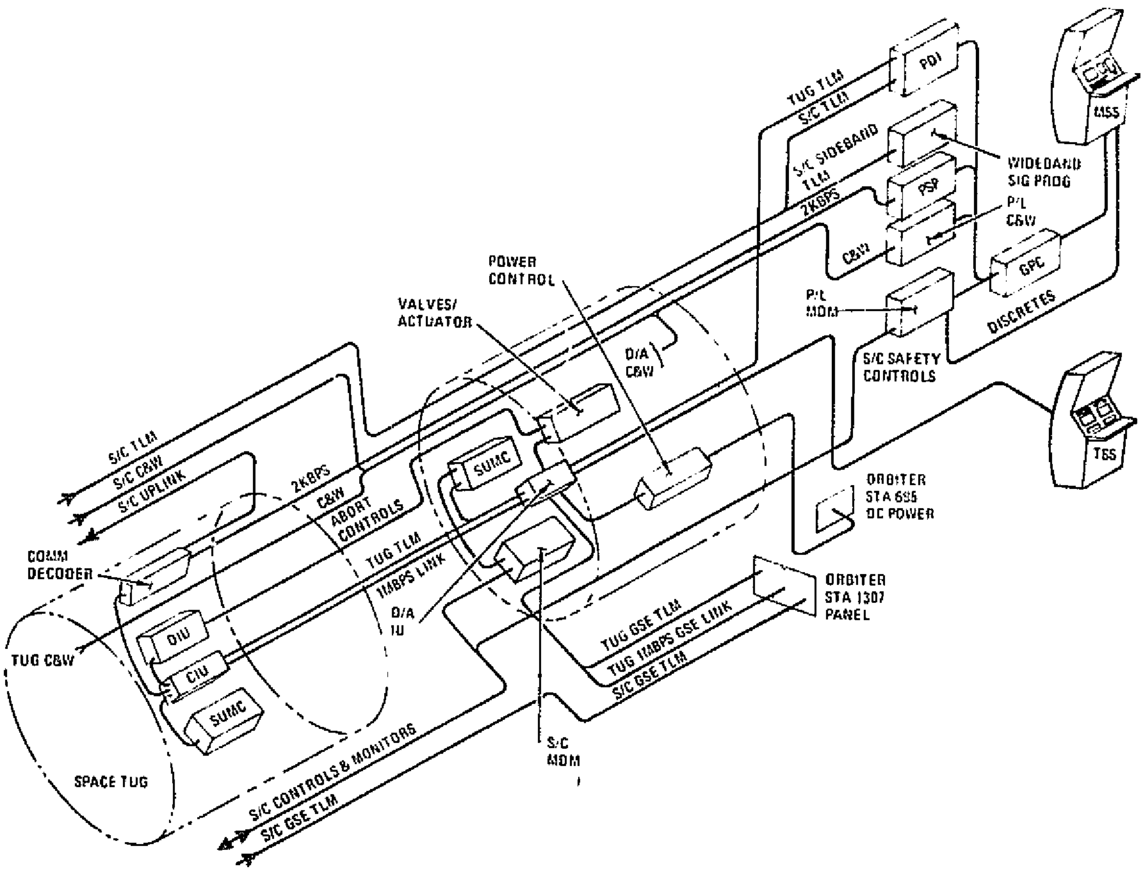

Figure 5. 1-5. Tug Specialist Station Concept/Deployment Adapter Processor

The major system-level differences between this and the baseline Tug/Orbiter interface concept (also high-autonomy Tug capability) is that a large portion of the Orbiter-supplied data processing requirements are eliminated. However, Tables 5. 1-7 and 5. 1-8 show that the Orbiter is still responsible for certain Tug support functions. These include: safety, RF communication with a deployed Tug (in the Orbiter vicinity), and attached Tug RF communications to ground routed through the Orbiter RF communication system. Thus, the Tug's physical interface to the Orbiter and into payload support avionics is not reduced via the use of this concept, and in fact is increased slightly to account for the communications link between the deployment adapter processor and the TSS control and monitor display (CRT and keyboard).

5. 1. 6 <u>CONCEPT EVALUATION.</u> To evaluate these four interface concepts, five sensitivity analyses were performed in the areas of: 1) interface minimization, 2) weight minimization, 3) crew effectivity, 4) software interface reduction, and 5) cost differences. These sensitivities and their results are presented in the following paragraphs.

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Table 5.1-7. Tug Interface Paths (Concept 4, Deployment Adapter Processor)

Phase	Function	Backup Requirement*	Up	Down	Up	Down	Comments
Prelaunch	Safety Critical	S	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	Operational B/U via gnd RF/PSP link
	Operations	O	Tug T-0 Data Link	Tug T-0 TLM Link	Tug T-0 Data Link 2	Tug T-0 TLM Link 2	TLM via Orbiter is alternative (RF or umbilical)
	Power	S	Orb Sta 695 Ded Fuel Cell	-	Orb Sta 695 Main Bus	-	Deployment adapter power through Orb Sta 1307
Ascent	Safety Critical	S	PSP - GPC No. 1	C&W to MSS TLM - PSP	PSP - GPC No. 2	TLM - PSP No. 2	
	Abort	S	PSP to DMS	TLM via PSP	PSP to CIU & D/A IU	PSP No. 2	Operational B/U via gnd RF/PSP
	Ground Comm	C	PSP	PSP	PSP 2	PSP 2	
	Power	S	Tug Fuel Cells (2)	-	Orb Sta 695	-	Deployment adapter power through Orb Sta 1307
On-Orbit Attached	Safety Critical Abort Ground Comm Power		Same as ascent				
	Operations	O	PSP - GPC PSP-C/O from Gnd	PSP to GPS PSP to Gnd	PSP 2 GPC -	PSP 2 GPC PSP 2 Gnd	
On-Orbit Detached	Safety Critical	S	PI	PI	PI 2	PI 2	Arm, Safing & loiter RF commands
	Operations	R	Gnd Net	Gnd Net	Gnd Net 2	Gnd Net 2	PI is backup for less than 20 miles

*S = Safety
R = Mission Reliability
C = See comments
O = Operational Convenience

Table 5.1-8. Concept 4, Deployment Adapter Processor Operations Allocation

	Controller/Monitor			
	Ground	Orbiter	Tug	D/A Processor
CONTROLS				
Safety Critical		B/U		X
Communications				X
Vents			X	
Purges			X	
Update G&N		X		
Umbilical Mechanisms				X
Forward Latches		X		
D/A Rotation				X
D/A Latches				X
Fuel Cell Activation				X
Power Changeover				X
Predeployment Checkout				X
ACS Arming	B/U	X		
Loiter	B/U	X		
Main Propulsion Arming	B/U	X		
Mission Sequence Start	B/U	X		
Main Propulsion Safing	B/U	X		
Propellant Dump	X	B/U		
Precapture Checkout	X			
ACS Safing	B/U	X		
Fuel Cell Deactivation				X
Abort		X		B/U
MONITORS				
C&W	B/U - Deployed	X - Deployed		X - Attached
Tug Status	B/U - Deployed	X - Deployed		X - Attached

Interface Minimization. The size of the Tug/Orbiter wiring interface was investigated for each of the four interface concepts. The results indicate that the size of the Tug/Orbiter physical interface is relatively independent of the concept selected (Table 5.1-9). These interfaces are required to satisfy safety ground rules or because practical concept implementation must employ, or be routed through, Orbiter equipment. Thus, unless basic Tug/Orbiter ground rules are changed (such as not requiring the Orbiter to monitor caution and warning (C&W) signals and transmitting Tug C&W data to ground), interface size benefit cannot be considered as concept selection criteria. This fact is especially true in light of the small size (16 TSP) of the recommended baseline interface concept.

Table 5.1-9. Tug/Orbiter Avionics Interfaces vs Interface Concept

Interface	Increased Ground Control	Baseline	Autonomous Tug	D/A Processor
C&W Monitors	17	17	17	17
TLM	2 @ 16K BPS*	2 @ 16K BPS*	2 @ 16K BPS*	2 @ 16K BPS*
Time Codes	1	1	1	1
Uplink (NASA Mission)	2*	2*	2*	2*
Uplink (DOD Mission)	2*	2*	2*	2*
Uplink (RF detached)	2*	2*	2*	2*
TSS or D/A TLM	2	2	2	2
Prelaunch (T-0 Panel)	2	2	2	2

*Includes Redundancy

NOTE: The number of communication channels is indicated above, not wire counts.

Crew Effectivity. A crew effectivity analysis for the four interface concepts was performed to evaluate the effects of each concept with respect to crew time required. The results were then compared with the baseline concept to determine the benefits or penalties associated with each alternative concept. The results of three of the four concepts are shown in Table 5.1-10 and indicate that: 1) the Orbiter commander and pilot work load is relatively independent of the interface concept choice; and 2) the mission specialist work load is reduced by 76 minutes, 68 minutes, and 32 minutes respectively for the maximum ground, high autonomy, and D/A processor concepts. The total crew time for the D/A processor concept is equal to that of the baseline.

Table 5.1-10. Crew Time Requirements vs Operational Concepts

Phase	Operational Concepts												
	Baseline			Max Ground Control			High Autonomy Tug			Processor in D/A			
	C	P	MS	C	P	MS	C	P	MS	C	P	MS	TS
Prelaunch	0	0	:20	0	0	:20	0	0	:20	0	0	:20	:20
Launch to Orbit	0	0	30:10	0	0	:05	0	0	:05	0	0	:05	30:05
Predeploy & Deploy	9:00	41:00	36:00	9:00	30:10	3:00	9:00	36:30	10:00	9:00	41:00	2:00	34:00
Return Rendezvous & Capture	43:00	58:00	31:30	43:00	39:30	17:30	43:00	56:30	19:30	43:00	58:00	29:30	2:00
Descent	0	0	2:00	0	0	2:00	0	0	2:00	0	0	0	2:00
Mission Totals	52:00	99:00	100:00	52:00	69:40	23:55	52:00	95:00	31:55	52:00	99:00	31:55	68:25

Note: C = Captain, P = Pilot, MS = Mission Specialist

Thus, the 32 minute mission specialist time saved is actually picked up by the Tug specialist duties (operating Tug support equipment located at the PSS) associated with this concept. The result of the maximum Orbiter control concept (not shown in table) will result in a significant increase in mission specialist (or Tug specialist) duties of approximately 83 minutes. This additional time would be used to perform the detailed data checkout and analysis tasks, and Tug RF control and monitor tasks that are allocated to ground facilities in the baseline configuration.

The result of this analysis indicates that the maximum ground control and high autotonomy Tug concepts offer the greatest benefit to the Orbiter crew from the standpoint of reducing crew time required to support Tug activities. Both these alternative concepts, however, have cost, and Orbiter operational complexity penalties that must be considered before a change to the baseline is recommended.

Weight Effects. An analysis was performed to determine the weight increases (with respect to the baseline) resulting from the various interface concepts. It was concluded that Concepts 1, 2, and 3 resulted in no significant weight increase or decrease. (All interface, Tug, D/A, and Orbiter interface equipment is the same as for the baseline.) Concept 4 (D/A processor concept), however, results in an Orbiter/deployment adapter weight increase of approximately 92 pounds (42 kg) (33 lb, 15 kg of payload weight). This weight increase is considered quite small and can be made even less significant if the D/A processor and TSS equipment were used to support Tug spacecraft functions. If used in this manner a net Orbiter/deployment adapter weight penalty of approximately 45 pounds (20 kg) (16 lb, 7 kg of payload weight) would result (Table 5.1-11). It is therefore concluded that no significant weight differences result from the interface concept selected and that weight should not be an important selection criterion.

Software Effects. An analysis was conducted to determine the major software differences between the various interface concepts. For this analysis the number of words of Tug support software was estimated for the data processors in the ground support equipment, the Orbiters GPC, the Tug (interface software only), and the deployment adapter processor (Concept 4 only). The results of this analysis are presented in Tables 5.1-12 through 5.1-16 and summarized in the results section below.

The data indicates that Concept 3 (high autonomy Tug) results in the least total amount of software (50k words) and the least amount of Orbiter support software (3k words) for the concepts studied. However, it also results in the greatest amount of more expensive Tug software (32k words), and the lowest amount of less expensive ground software.

Concept 1, on the other hand, requires a total of 63k words of which 14k words are of the airborne type and 49k words of the less expensive ground type. Although Concept 1 is attractive from the software cost standpoint, the additional ground hardware and

Table 5.1-11. Weight Penalty for D/A Processor Concept

Change (from Baseline)			Weight Difference lb	(kg)
Remove Spacecraft Wires from Station 1307 to P/L MDM			-67	(-30.4)
Add 1 Mbps Data Link Wires from TSS to D/A			+6	(+2.7)
Add TSS Equipment	lb	(kg)	+52	(+23.6)
2 CRT's	30	(13.6)		
2 Keyboards	4	(1.8)		
1 Display Electronics	15	(6.8)		
Harnessing	3	(1.4)		
Add D/A S/C MDM			+20	(+9.1)
Add D/A Processor			+34	(+15.4)
Total Weight Δ			+45	(+20.4)
Equivalent Payload Deployment Penalty (Orbiter Wt × 0.36)			16.2	(7.3)

personnel may offset this benefit. Other disadvantages are that a greater number of series hardware/software systems (Tug control facility, tracking stations, and Orbiter equipment) must be operational for mission success.

Concept 2 (high Orbiter capability) eliminates most of the ground facilities and software (as does Concept 3) and thus incurs long term operational cost advantages. This concept requires a greater interface with the Orbiter than Concept 3 and is thus considered less desirable.

Concept 4 reduces the actual Orbiter GPC required software to 4 K words (same as Concept 2) at the expense of an additional 17 K words of airborne software associated with the deployment adapter processor. The total amount of software required for this concept is approximately 74 K words and thus represents the maximum of the four methods investigated. Concept 4, however, provides some additional benefit in that a

Table 5.1-12. Software Requirements vs Control/Monitor Concept for Baseline

Software Option Name/Function	Baseline Option	Software Location & Storage Required (Number of Words) Ground	Orbiter	Tug	D/A
TUG CAUTION, WARNING & ABORT OPTIONS					
Execute Tug Critical Function Status Monitor	101		700	1,500 (Safety)	
Execute Tug Abort Mode 1 or 2, x	102		150	1,000 (Formatter) 400 (Cmd. Decoder)	
TUG INITIALIZATION, STATUS DISPLAY					
Execute Tug Initialization	201		500	600	
Execute Tug State Vector, Update	202		200		
Execute Command Tug Fuel Cell ON/OFF	203		20		
Execute Command Tug Communications ON/OFF	204		20		
Execute Tug Predeployment Status Display	205		2,000	6,200 (Status)	
Execute Tug Post Capture Status Display	206		2,000		
Execute Tug Post Capture Safe	207		150		
TUG DEPLOYMENT/CAPTURE OPTIONS					
Execute Deploy Arm/Safe Switch to xxxxx	301		40		
Execute Retract/Engage Fluid Umbilical	302		40		
Execute Rotate D/A Up/Down xxxxx	303		40		
Execute Retract/Engage Electrical Umbilical	304		40		
Execute Engage/Release Capture Latches	305		40		
TUG RF CONTROL OPTIONS					
Execute APS Arm/Safe and Switch to xxxxx	401	(200)	45		
Execute Main Propulsion Arm/Safe Switch to xxxxx	402	200	(45)		
Execute Tug Loiter Mode	403	200	(45)		
Execute State Vector Update	404	200	(45)		
Execute Go to Flight Command	405	200	(45)		
Execute Precapture Status Display	406		2,000		
Execute Precapture C/O		5,000			
TUG CONTROL & UTILITY OPTIONS					
Execute Switch to Orbiter Power	501		20		
Execute Switch to Tug Internal Power	502		20		
Execute Switch Tug Power OFF	503		20		
Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)	504		65		
Execute Output Tug-D/A Control Status	505		250		
Execute Load Tug DMS Loc xxx with xxxxx	506		45		
Execute Read Tug DMS Loc xxx with xxxxx	507		45		
Execute Display Tug TLM xxx continually	508		40		
OTHER TUG I/F SOFTWARE					
Rendezvous & Docking Control		15,000			
Tug Predeployment C/O		20,000			
Tug Precapture Safing		2,000			
Common Storage, Tables, etc.			1,500		
Note 1: (X) Backup Capability	Totals	43,000	10,170	9,700	

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Table 5.1-13. Software Requirements vs Control/Monitor Concept 1, Increased Ground Control

Software Option Name/Function	Baseline Option	Software Location & Storage Required (Number of Words)			
		Ground	Orbiter	Tug	D/A
TUG CAUTION, WARNING & ABORT OPTIONS					
Execute Tug Critical Function Status Monitor	101		700	1,500 (Safety)	
Execute Tug Abort Mode 1 or 2, x	102		150	1,000 (Formatter) 400 (Cmd. Decoder)	
TUG INITIALIZATION, STATUS DISPLAY					
Execute Tug Initialization	201			600	
Execute Tug State Vector, Update	202				
Execute Command Tug Fuel Cell ON/OFF	203				
Execute Command Tug Communications ON/OFF	204				
Execute Tug Predeployment Status Display	205			6,200 (Status)	
Execute Tug Post Capture Status Display	206				
Execute Tug Post Capture Safe	207				
TUG DEPLOYMENT/CAPTURE OPTIONS					
Execute Deploy Arm/Safe Switch to xxxxx	301		40		
Execute Retract/Engage Fluid Umbilical	302				
Execute Rotate D/A Up/Down xxxxx	303				
Execute Retract/Engage Electrical Umbilical	304				
Execute Engage/Release Capture Latches	305				
TUG RF CONTROL OPTIONS					
Execute APS Arm/Safe and Switch to xxxxx	401	(200)	45		
Execute Main Propulsion Arm/Safe Switch to xxxxx	402	200	(45)		
Execute Tug Loiter Mode	403	200	(45)		
Execute State Vector Update	404	200			
Execute Go to Flight Command	405	200			
Execute Precapture Status Display	406		2,000		
Execute Precapture C/O		5,000			
TUG CONTROL & UTILITY OPTIONS					
Execute Switch to Orbiter Power	501	20			
Execute Switch to Tug Internal Power	502	20			
Execute Switch Tug Power OFF	503	20			
Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)	504	65			
Execute Output Tug-D/A Control Status	505	250			
Execute Load Tug DMS Loc xxx with xxxxx	506	45			
Execute Read Tug DMS Loc xxx with xxxxx	507	45			
Execute Display Tug TLM xxx continually	508	40			
OTHER TUG I/F SOFTWARE					
Rendezvous & Docking Control		15,000			
Tug Predeployment C/O		20,000			
Tug Precapture Safing		2,000			
Common Storage, Tables, etc.			700		
Note 1: (X) = Backup Capability	Totals	48,600	3,730	9,700	

Table 5.1-14. Software Requirements vs Control/Monitor Concept 2, High Autonomy Tug

Software Option Name/Function	Baseline Option	Software Location & Storage Required (Number of Words) Ground	Orbiter	Tug	D/A
TUG CAUTION, WARNING & ABORT OPTIONS					
Execute Tug Critical Function Status Monitor	101		350	2,500 (Safety)	
Execute Tug Abort Mode 1 or 2, x	102		45	1,000 (Formatter) 400 (Cmd. Decoder)	
TUG INITIALIZATION, STATUS DISPLAY					
Execute Tug Initialization	201		45	600	
Execute Tug State Vector, Update	202		200		
Execute Command Tug Fuel Cell ON/OFF	203		20		
Execute Command Tug Communications ON/OFF	204		20		
Execute Tug Predeployment Status Display	205		200	6,200 (Status)	
Execute Tug Post Capture Status Display	206		200		
Execute Tug Post Capture Safe	207		45		
TUG DEPLOYMENT/CAPTURE OPTIONS					
Execute Deploy Arm/Safe Switch to xxxxx	301		40		
Execute Retract/Engage Fluid Umbilical	302		40		
Execute Rotate D/A Up/Down xxxxx	303		40		
Execute Retract/Engage Electrical Umbilical	304		40		
Execute Engage/Release Capture Latches	305		40		
TUG RF CONTROL OPTIONS					
Execute APS Arm/Safe and Switch to xxxxx	401		45		
Execute Main Propulsion Arm/Safe Switch to xxxxx	402		45		
Execute Tug Loiter Mode	403		45		
Execute State Vector Update	404		45		
Execute Go to Flight Command	405		45		
Execute Precapture Status Display	406		200		
Execute Precapture C/O				5,000	
TUG CONTROL & UTILITY OPTIONS					
Execute Switch to Orbiter Power	501		20		
Execute Switch to Tug Internal Power	502		20		
Execute Switch Tug Power OFF	503		20		
Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)	504		65		
Execute Output Tug-D/A Control Status	505		250		
Execute Load Tug DMS Loc xxx with xxxxx	506		45		
Execute Read Tug DMS Loc xxx with xxxxx	507		45		
Execute Display Tug TLM xxx continually	508		40		
OTHER TUG I/F SOFTWARE					
Rendezvous & Docking Control		15,000			
Tug Predeployment C/O				20,000	
Tug Precapture Safing				2,000	
Common Storage, Tables, etc.			1,000		
Note 1: (X) - Backup Capability	Totals	15,000	2,905	31,500	

Table 5.1-15. Software Requirements vs Control/Monitor Concept 3, Increased Orbiter Capability

Software Option Name/Function	Baseline Option	Software Location & Storage Required (Number of Words) Ground	Orbiter	Tug	D/A
TUG CAUTION, WARNING & ABORT OPTIONS					
Execute Tug Critical Function Status Monitor	101		700	1,500 (Safety)	
Execute Tug Abort Mode 1 or 2, x	102		150	1,000 (Fomatter) 400 (Cmd. Decoder)	
TUG INITIALIZATION, STATUS DISPLAY					
Execute Tug Initialization	201			600	
Execute Tug State Vector, Update	202		200		
Execute Command Tug Fuel Cell ON/OFF	203		20		
Execute Command Tug Commumications ON/OFF	204		20		
Execute Tug Predeployment Status Display	205		2,000	6,200 (Status)	
Execute Tug Post Capture Status Display	206		2,000		
Execute Tug Post Capture Safe	207		150		
TUG DEPLOYMENT/CAPTURE OPTIONS					
Execute Deploy Arm/Safe Switch to xxxxx	301		40		
Execute Retract/Engage Fluid Umbilical	302		40		
Execute Rotate D/A Up/Down xxxxx	303		40		
Execute Retract/Engage Electrical Umbilical	304		40		
Execute Engage/Release Capture Latches	305		40		
TUG RF CONTROL OPTIONS					
Execute APS Arm/Safe and Switch to xxxxx	401		45		
Execute Main Propulsion Arm/Safe Switch to xxxxx	402		(45)		
Execute Tug Loiter Mode	403		(45)		
Execute State Vector Update	404		(45)		
Execute Go to Flight Command	405		(45)		
Execute Precapture Status Display	406				
Execute Precapture C/O			5,000		
TUG CONTROL & UTILITY OPTIONS					
Execute Switch to Orbiter Power	501		20		
Execute Switch to Tug Internal Power	502		20		
Execute Switch Tug Power OFF	503		20		
Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)	504		65		
Execute Output Tug-D/A Control Status	505		250		
Execute Load Tug DMS Loc xxx with xxxxx	506		45		
Execute Read Tug DMS Loc xxx with xxxxx	507		45		
Execute Display Tug TLM xxx continually	508		40		
OTHER TUG I/F SOFTWARE					
Rendezvous & Docking Control		15,000			
Tug Predeployment C/O			20,000		
Tug Precapture Safing			2,000		
Common Storage, Tables, etc.			1,500		
Note 1: (X) = Backup Capability	Totals	15,000	35,170	9,700	

Table 5.1-16. Software Requirements vs Control/Monitor Concept 4, Processor in Deployment Adapter

Software Option Name/Function	Baseline Option	Software Location & Storage Required (Number of Words)			
		Ground	Orbiter	Tug	D/A
TUG CAUTION, WARNING & ABORT OPTIONS					
Execute Tug Critical Function Status Monitor	101		700	1,500 (Safety)	700
Execute Tug Abort Mode 1 or 2, x	102		150	1,000 (Fomatter) 400 (Cmd. Decoder)	150
TUG INITIALIZATION, STATUS DISPLAY					
Execute Tug Initialization	201			600	500
Execute Tug State Vector, Update	202		200		
Execute Command Tug Fuel Cell ON/OFF	203				20
Execute Command Tug Communications ON/OFF	204				20
Execute Tug Predeployment Status Display	205			6,200 (Status)	2,000
Execute Tug Post Capture Status Display	206				2,000
Execute Tug Post Capture Safe	207				150
TUG DEPLOYMENT/CAPTURE OPTIONS					
Execute Deploy Arm/Safe Switch to xxxxx	301				40
Execute Retract/Engage Fluid Umbilical	302				40
Execute Rotate D/A Up/Down xxxxx	303				40
Execute Retract/Engage Electrical Umbilical	304				40
Execute Engage/Release Capture Latches	305				40
TUG RF CONTROL OPTIONS					
Execute APS Arm/Safe and Switch to xxxxx	401	(200)	45		
Execute Main Propulsion Arm/Safe Switch to xxxxx	402	200	(45)		
Execute Tug Loiter Mode	403	200	(45)		
Execute State Vector Update	404	200	(45)		
Execute Go to Flight Command	405	200	(45)		
Execute Precapture Status Display	406		2,000		
Execute Precapture C/O		5,000			
TUG CONTROL & UTILITY OPTIONS					
Execute Switch to Orbiter Power	501				20
Execute Switch to Tug Internal Power	502				20
Execute Switch Tug Power OFF	503				20
Execute Tug-D/A (xx) Actuator xx to xxx (ON/OFF)	504				65
Execute Output Tug-D/A Control Status	505				250
Execute Load Tug DMS Loc xxx with xxxxx	506				45
Execute Read Tug DMS Loc xxx with xxxxx	507				45
Execute Display Tug TLM xxx continually	508				40
OTHER TUG I/F SOFTWARE					
Rendezvous & Docking Control		15,000			
Tug Predeployment C/O		20,000			
Tug Precapture Safing		2,000			
Common Storage, Tables, etc.			700		
D/A Processor Time Share Executive					10,449
Note 1: (X) – Backup Capability	Totals	43,000	3,975	9,700	16,694

large portion of the software (12 K words) required can be managed and controlled via a single government agency. This benefit is somewhat offset by requiring the Orbiter crew to be familiar with two hardware/software operating systems (TSS & Orbiter DPC).

Results and Recommendations. Four alternative techniques for performing Tug monitor and control were evaluated with respect to the recommended Tug implementation concept to determine interface impacts.

Evaluation criteria consisted of Orbiter and crew safety, Orbiter hardware/software interface complexity, operational complexity, crew effectivity, and cost. For each technique evaluated a control and monitor allocation plan was established to define primary and backup responsibility for all major Tug flight operational phases involving Tug/Shuttle operations. Concept advantages and penalties were then determined for each technique to allow comparison with the recommended Tug baseline. The results of this evaluation are summarized in Figure 5.1-6.

The cost differences for the four concepts and the baseline are shown over a five-year period in Figure 5.1-7. This data indicates that costwise the high autonomy Tug (Concept 3) ultimately is the best choice but does not begin to pay for itself until its ninth operational year when compared to the baseline (fifth operational year when

EVALUATION CRITERIA	BASELINE	INCREASED GROUND CONTROL	HIGH AUTONOMY (RED / GREEN)	INCREASED ORBITER	D/A PROCESSOR/TSS
SAFETY	RF & HARDWIRE C&W TO ORBITER	SAME AS BASELINE	SAME AS BASELINE NO GND B/U	SAME AS BASELINE NO GND B/U	SAME AS BASELINE ORBITER B/U TO TSS
ORBITER I/F	ORBITER SUPPORT EQUIP	ORBITER SUPPORT EQUIP	ORBITER SUPPORT EQUIP	ORBITER SUPPORT EQUIP	ORBITER SUPPORT EQUIP
HARDWARE	+3 PANELS	+2 PANELS	+3 PANELS	+3 PANELS	+ TSS (CRT + KED)
ORBITER S/W	10K	8K	3K	53K	4K + 17K (TSS)
TUG S/W	10K	16K	52K	10K	10K
GND FLT S/W	44K	60K	10K	15K	43K
TOTAL (WORDS)	[illegible]	[illegible]	[illegible]	[illegible]	74K
OPERATIONAL COMPLEXITY	REFERENCE 3 MAN ORBITER CREW • GND STA FOR GND B/U	• INCREASE GND [illegible] • [illegible] TO ORBITER [illegible] • MORE INTERFACES THAN BASELINE	• GND STA ONLY [illegible] FOR R&D	SPECIAL CREW TRAINING FOR O/C DETAILED TUG KNOWLEDGE	• POSSIBLE 4 MAN CREW • INCREASED GND TEST • P/L INTEGRATION BY CONTROLLED SINGLE AGENCY
COST (Δ 5 PROGRAMS)	REFERENCE	[illegible]	[illegible]	+ 8 [illegible]	+ 6 [illegible]
CREW TIME MINUTES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 5.1-6. Summary of Tug Orbiter Ground Operations Sensitivity

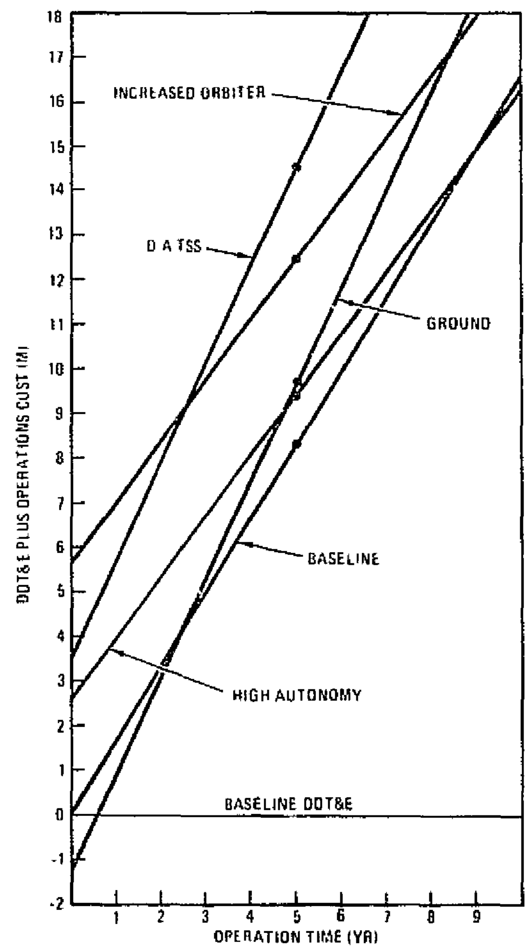


Figure 5.1-7. Cost Assessment of Interface Concepts

compared to increased ground control (Concept 1). Increased ground control provides initial development cost benefits at the expense of increased ground/Orbiter operational costs and some decrease in Orbiter interface complexity. When compared to the baseline configuration, this cost benefit disappears after two years of operation, due primarily to larger ground crew requirements to support the total ground control concept. Greater Orbiter support (Concept 2) increased initial development costs and Tug/Orbiter operational complexity and is not recommended.

In general the four concepts are comparable with respect to Orbiter and crew safety, Orbiter interface size, power and weight requirements, and use of Orbiter-supplied payload support equipment (GPC, PI, PSP, MDM, MTU, etc.). Aft cabin payload-unique support equipment consists of three control panels (abort, deploy/capture, initialization) for the baseline and Concepts 2 and 3, while Concept 1 requires only two control panels (abort and RF portion of deploy/capture panel). The greatest differences between the various concepts (1, 2, and 3) and the baseline occur in the amount of Orbiter/Tug/ground software required and the crew time required to support Tug activities.

Greater differences in Orbiter interface requirements result when the baseline is compared to Concept 4 (deployment adapter/TSS). The addition of components in the D/A and crew area results in a net spacecraft weight penalty of 16 pounds (7.3 kg) for a delivery mission. The Tug specialist station would require an additional 200 watts while the D/A processor and S/C MDM would use another 100 watts. The Tug/Orbiter interface would increase by a data link from the aft crew station to the D/A and a power connection for the added equipment. No Tug/Orbiter interfaces can be deleted from the baseline. However, if spacecraft control and monitor hardwires normally routed to the Orbiter were routed to the deployment adapter processor, a significant Orbiter/payload interface reduction could result. For Concept 4, total program costs, including DDT&E of hardware and software as well as recurring costs, would be increased by 6.1 million dollars. One contributor to the increased costs is a net increase of 11 K computer memory words, even though Orbiter GPC support software would decrease by 6 K words. Total crew tasks would be essentially identical, but the mission

specialist would be required to interface with two independent computers which could result in confusion in certain situations. An alternative would be to use a fo rth crew man for Tug and payload support functions.

The TSS/deployment adapter processor does, however, have potential benefits that may outweigh the penalties previously discussed. If both Tug and Tug payload were to use the TSS then more efficient integration of payload interfaces and operations might result. This is because the integration and interface modifications involved would not significantly impact the Orbiter contractor or NASA/JSC.

In summary, it is recommended that the baseline interface concept described in Section 4.6 of Volume II be continued for monitor and control requirements development. The control and monitoring operational allocation responsibilities for this concept are shown in Table 5.1-17.

This configuration includes recommendations from the various sensitivity analyses and from coordination meetings among NASA/MSFC and the five Tug study contractors. In this configuration, the Orbiter is the safing and abort control center and thus is prime for performing these functions (with ground backup). Similarly, the Orbiter is prime for normal on-orbit operations such as status determination and deployment/capture operations where Orbiter equipment is involved in the operations and direct crew involvement is desired or operationally efficient.

Table 5.1-17. Recommended Interface Operations Allocation

OPERATION	GROUND	ORBITER	TUG
MONITORS			
C&W	B/U	X	
TUG STATUS	B/U	X	
CONTROLS			
SAFETY CRITICAL	B/U	X	
VENTS	B/U	B/U	X
PURGES	B/U	B/U	X
UPDATE G&N	B/U	X	
UMBILICAL MECHANISMS		X	
FORWARD LATCHES		X	
D/A ROTATION		X	
D/A LATCHES		X	
FUEL CELL START	X	B/U	
FUEL CELL STOP	B/U	X	
POWER CHANGEOVER		X	
PREDEPLOYMENT CHECKOUT	X		
PREDEPLOYMENT STATUS	B/U	X	
ACS ARMING	B/U	X	
ENGINE NOZZLE	X	B/U	
LOITER	X	B/U	
MAIN PROPULSION ARMING	X	B/U	
MISSION SEQUENCE START	X	B/U	
MAIN PROPULSION SAFING	X	B/U	
PROPELLANT DUMP	X		
PRECAPTURE CHECKOUT	X		
ACS SAFING	B/U	X	
FUEL CELL DEACTIVATION	B/U	X	
ABORT		X	

Ground control is prime for checkout operations involving detailed data analysis, large data processing hardware/software activities, and for operations where detailed knowledge of the Tug or its subsystems is needed. In addition, the ground will assume prime responsibility for Tug control once it is deployed from the Orbiter (after release and initiation of Tug APS system by Orbiter RF command).

The current Orbiter support capability (JSC 07700, Vol. XIV) to support Orbiter payload appears adequate (with rather minor changes) for Tug/Spacecraft requirements. It is therefore also recommended that the Orbiter capability for

Tug/payload support be adopted as the baseline, and the appropriate change requests against Orbiter accommodations be used to effect the required Orbiter changes. The TSS concept should be retained as a potential fall-back position in the event that presently documented Orbiter support capability is not actually being implemented or that integration is more difficult than indicated by JSC 07700. It is further recommended that if the TSS concept is adopted it should be a GFE option available to all payloads (to avoid penalizing any one payload for concept DDT&E).

5.2 SECURE COMMUNICATIONS

Department of Defense requirements may cause incorporation of security (COMSEC) units on Tug, its payload, and on the Orbiter to avoid vehicle (payload) spoofing, or unauthorized communication of monitoring or command data. This task assessed the impact to the Tug/Orbiter avionics interfaces and operations resulting from secure communications requirements implementation (Figure 5.2-1).

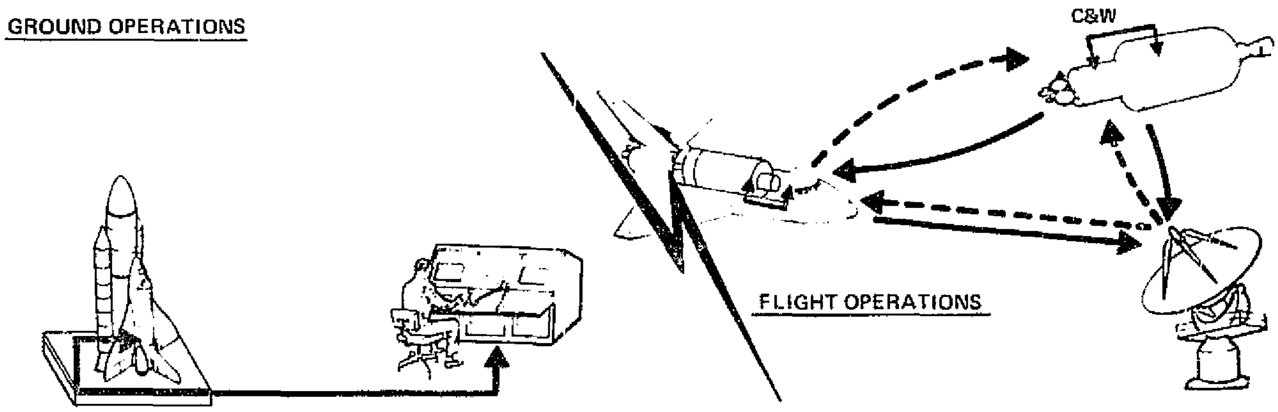


Figure 5.2-1. Tug Secure Communications

The objectives of this sensitivity task are to: 1) analyze the Tug command and data requirements to establish the need for communications security, 2) identify applicable security techniques to fulfill the Tug security requirements, 3) identify electronic and system interfaces, 4) perform a comparative analysis between the candidate systems, 5) select a baseline system, and 6) establish the characteristics of the selected technique. Four evaluation factors and their associated ground rules and assumptions which were employed are listed below.

<u>Mission Classification</u> — Two different DOD mission groupings are hypothesized: 1) missions requiring secure communications for command and telemetry links, and 2) missions requiring no secure communication or security for only the command link. Both groupings were analyzed in the subsequent discussion.

Launch Facility — The same launch facility was assumed for NASA and DOD missions. The impact of secure communications, directly on the launch facility and indirectly through vehicle configuration selection, is discussed in terms of checkout hardware and software, and the launch facility security operating considerations and modes.

Tug and Payload — The communication system must be designed to prevent classified plain language information, defined as red data, from appearing at detectable levels on lines that handle encrypted or unclassified information, defined as black data. Those vehicle functions requiring a secure communication link were tabulated. Based on this listing, the communication links were classified as secure or clear. Finally, various hardware options are presented for implementing the secure communication link.

Operating Procedures — A single crew has been assumed for removal of cryptographic devices not required for NASA missions. To establish the task objectives, the approach delineated in Figure 5.2-2 was adopted.

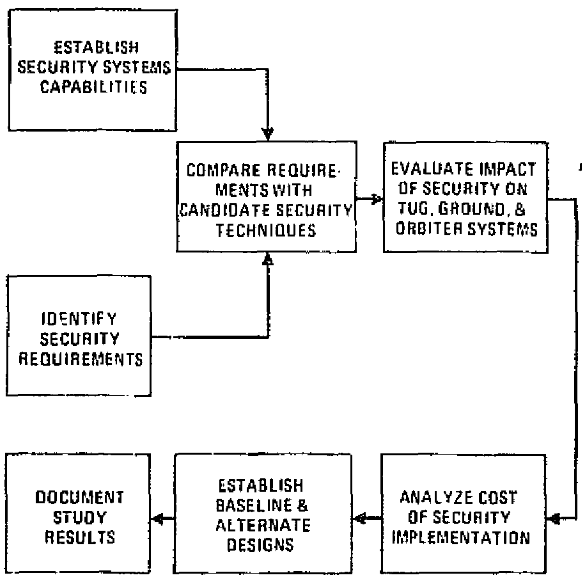


Figure 5.2-2. Secure Communications Sensitivity Approach

The development and implementation of secure communication requirements for Tug is contained in the next section; it is followed by the recommendations, sensitivity study conclusions, and references.

5.2.1 ANALYSES AND IMPLEMENTATION. Analytical effort has been segregated into six categories within this section. These are: security requirements analysis, security systems analysis, alternative technique analysis, implementation, ground support system requirements analysis, and the security implementation cost analysis, presented in Sections 5.2.1.1 through 5.2.1.6, respectively.

5.2.1.1 Security Requirements Analysis. Communications security requirements for the DOD missions of the Tug are controlled by AF Regulation 205-7, which requires cryptographic devices in both the command and telemetry links unless a waiver has been granted by HQ USAF. The controlling consideration that determines the advisability of a waiver is the potential for mission compromise via either the command or telemetry link. The following paragraphs contain a discussion of the information being processed by these links and the resultant impact on the mission.

Command System — In the attached mode, a hardline command link is maintained between the Tug and the Orbiter. In the detached mode, an RF command link is maintained with the Orbiter and with the ground network.

Typical Tug command requirements are presented in Table 5.2-1. As indicated in the table, the Tug uses two types of commands: instruction commands for computer update, and discrete commands processed by the Tug signal processor. Instruction commands, which are 32 bit words (or two 16 bit words), may consist of a few words for navigation update or as many as 1000 words of computer memory load.

Command data may be considered sensitive either because of mission information contained in the command, such as guidance update, or because commands received at the wrong time can be catastrophic to the mission. As can be seen from Table 5.2-1, the Tug employs a guidance update prior to separation from the Orbiter. The guidance data, properly interpreted, supplies information about the orbit of the Tug boosted spacecraft, which may compromise the spacecraft mission.

Mission commands sent inadvertently or in an attempt to spoof the Tug need not be sensitive commands to damage the mission. A simple control command such as "SAFE ACS" or "LOITER" received at the wrong time in the mission profile can have very serious consequences.

Since the missions have the possibility of being spoofed and use potentially sensitive command data in the form of guidance updates, the Tug baseline design for DOD missions should be configured with an encrypted command link.

The hardline command link from the Orbiter to the Tug does not necessarily have to be encrypted to maintain command security. However, operating the link in a clear mode while attached, and in a secure mode for the detached RF link, would require dual interfaces with the Orbiter or an encryption bypass mode. Also the command data on the hardline would be considered as "red" (sensitive) data and would require TEMPEST shielding to isolate the line from the system "black" (clear) lines. Dual mode operation (clear/encrypted) adds complexity to the system and does not yield an equipment or cost savings. Therefore the Tug baseline design should use an encrypted command link for both attached and detached DOD operations.

Data System — The Tug downlink data requirements are: 1) telemetry data, 2) slow scan TV for inspection or rendezvous, and 3) Orbiter crew voice communications concerning the mission. The Tug telemetry system generates PCM data at a bit rate of 16 Kbps, which is tranmitted to the Orbiter by hardline or S-band RF link, and to the SCF ground network by the S-band link. Encryption of telemetry data will be required if the data is sensitive (i.e., sensor data) or if it reveals mission operation characteristics. Some Tug missions may be candidates for telemetry link security on the basis of revealing mission status and vehicle targeting. Vehicle status measurements,

Table 5.2-1. Typical Tug Command List

Command	Pre-Deployment	Post-Deployment
DMS Instruction		
Display Data	X	
Strobe Output	X	
Enable Task	X	
Disable Task	X	
Load Data/Program	X	X
Nav State Vector		
Guidance Target Data		
Data Use Enable		
RF Commit		
Enable RF	X	
Enable ACS		X
Arm ACS		X
Safe ACS		X
Enable Main Propulsion System		X
Arm Main Propulsion System		X
Safe Main Propulsion System		X
Verify Program Memory	X	X
Arm Program		X
Disarm Program		X
Tug Precapture Safing		X
Pause	X	
Loiter Mode		X
Encryptor Bypass (A & B)	X	X
Encryptor Activate (A & B)	X	X
Pseudo Random Noise Ranging On		X
Pseudo Random Noise Off		X
Transmitter A On	X	X
Transmitter B On	X	X
Transmitter A Off	X	X
Transmitter B Off	X	X
Enable Backup ACS		X

either from the Tug or from the spacecraft, may indicate vehicle problems or mission abort conditions that the spacecraft agency does not want advertised. Transmission of the Tug guidance data in the process of command verification or memory readout will supply information as to the final orbit of the spacecraft.

If the mission is not sensitive to either of these sources of possible compromise, the remainder of the telemetry data supplies little or no justification for a secure telemetry link.

TV data may be sensitive if the target being viewed is sensitive. For those cases, the slow scan TV system, which operates at approximately 60 Kbps, will require encryption. Since the voice link is an Orbiter-to-ground requirement but is not in the Tug baseline, voice security has not been considered in this study.

5.2.1.2 Security System Analysis. There are three candidate security systems for use on the DOD Tug missions. The systems and their mission applicability are as follows:

System	Application
KI-23	Command
KG-29	Command
KG-28	Command or Telemetry

The KG-28 system is capable of operating in either a data encryption or command decryption mode; however, its principal application is as an encryptor. There are two difficulties with using the unit in the command system; the unit does not supply the command authentication function, and there is a potential network incompatibility. Therefore, the KI-23 and KG-29 will be analyzed for the command system, and the KG-28 will be considered for the telemetry and TV application.

Command Systems — The physical and operational characteristics of the KI-23 and KG-29 systems are summarized in Table 5.2-2. The interface characteristics for the two systems are listed in Table 5.2-3.

As shown in Table 5.2-2, the KI-23 system is smaller, lighter, and uses less power than the KG-29 system, but on the other hand outputs fewer commands per second, and is limited to a 20 bit command message. The KG-29 command message may contain an unlimited number of bits when operating in the unauthenticated mode and will output commands at a rate that is limited only by the input bit rate and the message length.

The interface requirements for the two systems (Table 5.2-2) are sufficiently similar that their impact on the Tug subsystems will be the same. One possible exception is that the KG-29 system does not have an internal clock, but depends on the uplink clock for timing functions. Conditioning of the clock signal may be necessary to maintain the desired characteristics.

Telemetry System — The physical and operational characteristics of the KG-28 unit are shown in Table 5.2-4 and the interface requirements are listed in Table 5.2-5. The KG-28 is compatible with the Tug mission requirements.

Table 5.2-2. Command Decryptor Characteristics

	KIR-23	KGR-29	
Dimensions in. (cm)		Decryptor	P/S
Height	5.81 (14.8)	3.75 (9.5)	1.3 (3.3)
Width	3.60 (4.1)	4.5 (11.4)	4.0 (10.2)
Depth	6.02 (15.3)	9.75 (24.8)	7.5 (14.0)
Weight lb (kg)	4.4 (2.0)	6.5 (2.95)	1.8 (0.82)
Voltage	22 Vdc - 33 Vdc	+27.5 ±5.5 Vdc	
Power	2.4 W @ 28 Vdc	16 W @ 28 Vdc	
Data Input Rate	1 bps - 16 Kbps	1 bps - 100 Kbps	
Data Output Rate	500 bps	Same as input	
Format	14 bits or 20 bits	2 bits - unlimited (non-authenticate) 2 bits - 42 bits (authenticate)	
TLM Data Rate	1 bps - 128 Kbps	1024 Kbps maximum	

5.2.1.3 Alternative Technique Analysis. An alternative to using cryptographic devices to achieve command and telemetry security is to employ software algorithms in the Tug computer or to use an operational technique such as communicating only at preselected times or using very narrow beam antennas. A variation is to use a combination system of software and one or more of the operational methods. An additional possibility, beyond the scope of this study, but one that should be studied in depth, is the use of communication satellites and 60 GHz links that can't be jammed or intercepted from the ground (due to atmospheric phenomena at this frequency).

Software Security Implementation — The DMS computer proposed for the Tug is capable of performing encryption/decryption functions or of performing any one of several algorithms on received or transmitted data.

Use of the computer as a cryptographic device is not recommended because of the TEMPEST problems involved. Computers are not designed for this purpose and it would be very difficult to keep them from transmitting key text. For this reason the only software methods considered here are algorithms and stored secure commands.

Table 5.2-3. Command Decryptor Interface Requirements

Parameter	KIR-23 Decryptor	KGR-29 Decryptor
Input Signal		
True Level	+2.4V to +5.0V	+2.2V to +3.4V
False Level	-1.0V to +0.4V	-1.0V to +0.4V
Impedance	750Ω<Z<2.7KΩ, 100 pf	600Ω ±10%, 60 pf
Rise/Fall Time	5μ S maximum	0.05 BP< T<0.012 BP
Data Code	NRZ	NRZ
Clock Code	RZ	RZ
Output Signal		
True Level	+4.7V to +5.2V	+2.2V to +3.4V
False Level	-1.0V to +0.4V	-1.0V to +0.4V
Impedance	5KΩ, 1000 pf	93Ω ±10%, 60 pf
Data Code	NRZ	NRZ
Clock Output	Pulse width 75 μ S	4 μ S < T_p < 1 BP - 4 μ S
Control Signals	100 μS < PW< 2 CLK P	--
Increment	--	True
Execute/Reject	--	False
True Level		2.4V to 3.4V
False Level		-1.0V to 0.4V
Pulse Duration		Time from clock trailing to leading edge
Telemetry		
Gate Width	23 bit periods	36 bit periods
Input Clock	Pulse width = 10 μS	275 μS< T < 1 BP
TLM Output		
Signal	NRZ - 23 bits	NRZ - 36 bits
True Level	+4.7V to +5.2V	+2.2V to +3.4V
False Level	-1.0V to +0.4V	-1.0V to +0.4V
Load	600Ω, 7000 pf	93Ω ±10%, 60 pf

The computer can be programmed to perform add, subtract, or shift algorithms at a nominal impact on memory capacity on the order of 200 words. A variation of this technique involves a time sequence that selects a new algorithm at predetermined time intervals. Computer memory can also be used to store secure commands that are accessed from the ground by a special instruction command.

Table 5.2-4. Telemetry Encryptor

	KGX-28A
Dimensions in. (cm)	
Height	5.35 (13.6)
Width	4.28 (10.9)
Depth	5.78 (14.7)
Weight lb (kg)	4.25 (1.93)
Voltage	+27.5 ±5.5 Vdc
Power	7.0 W @ 27.5 Vdc
Data Input Rate	1 bps - 1.024 Mbps
Data Output Rate	Same as input

Operational Security Implementation — It is possible to achieve a degree of communications security by means of operational techniques such as:

a. Operation only over the geographical limits of the United States.

b. Operation only at predetermined times.

c. Use of very narrow beam antennas.

d. Autonomous operation.

The first two options are most useful for orbiting spacecraft with repetitive passes over the network ground stations. The Tug has a relatively short mission duration that involves contact with the Orbiter as well as with the ground network. The Tug mission includes separation from the Orbiter in a timed sequence that makes communication time windows impractical. Limiting communication to periods when the Tug is over the continental limits of the United States would place a severe restraint on the mission requirements of the payload being boosted by the Tug.

Narrow beam antennas can be used to control access to the data either between the Tug and Orbiter or the Tug and the ground network. For operation of this type, vehicle antennas used for command reception or data transmission must be pointed quite accurately at the transmitting or receiving source. Because the Tug baseline design uses a phased array, pointed narrow beam antennas are a possible option that should be studied in greater depth.

Table 5.2-5. Telemetry Encryptor Interface Requirements

Parameter	KGX-28A Encryptor
Input Signal	
True Level	+2.2V to +3.4V
False Level	-1.0V to +0.4V
Damage Level	-1.0 < L < 5.0V
Impedance	93Ω ±10%, 60 pf
Rise/Fall Time	0.05 BP < T < 0.10 BP
Data Code	NRZ
Clock Code	RZ
Output Signal	
True Level	+2.2V to +3.4V
False Level	-1.0V to +0.4V
Impedance	93Ω
Data Code	NRZ
Clock Output	--
Control Signals	
XMT/RECV	--
XMT Level	-1.0V to +0.4V
RECV Level	+2.2V to +3.4V
Mode A	
True Level	+2.2V to +3.4V
False Level	-1.0V to +0.4V

Autonomous operation of the Tug conflicts with Orbiter vicinity safety requirements, and the possible need to update the Tug GN&C system.

In summary, several alternative methods appear to have some promise for application on the Tug system. It is recommended that future investigations be conducted on algorithms, narrow beam antennas, and a 60 GHz communications satellite link.

5.2.1.4 Implementation. The electrical interface between the cryptographic equipment and the Tug subsystems are shown for the three candidate systems in Figure 5.2-3. The Orbiter subsystems do not have any interfaces directly with the Tug cryptographic equipment. The indirect effect of secure links between the Tug and the Orbiter is the imposition of compatible encryption and decryption systems and the use of interface harnessing capable of transferring black encrypted data or the red plain language information in a cryptographic bypass mode.

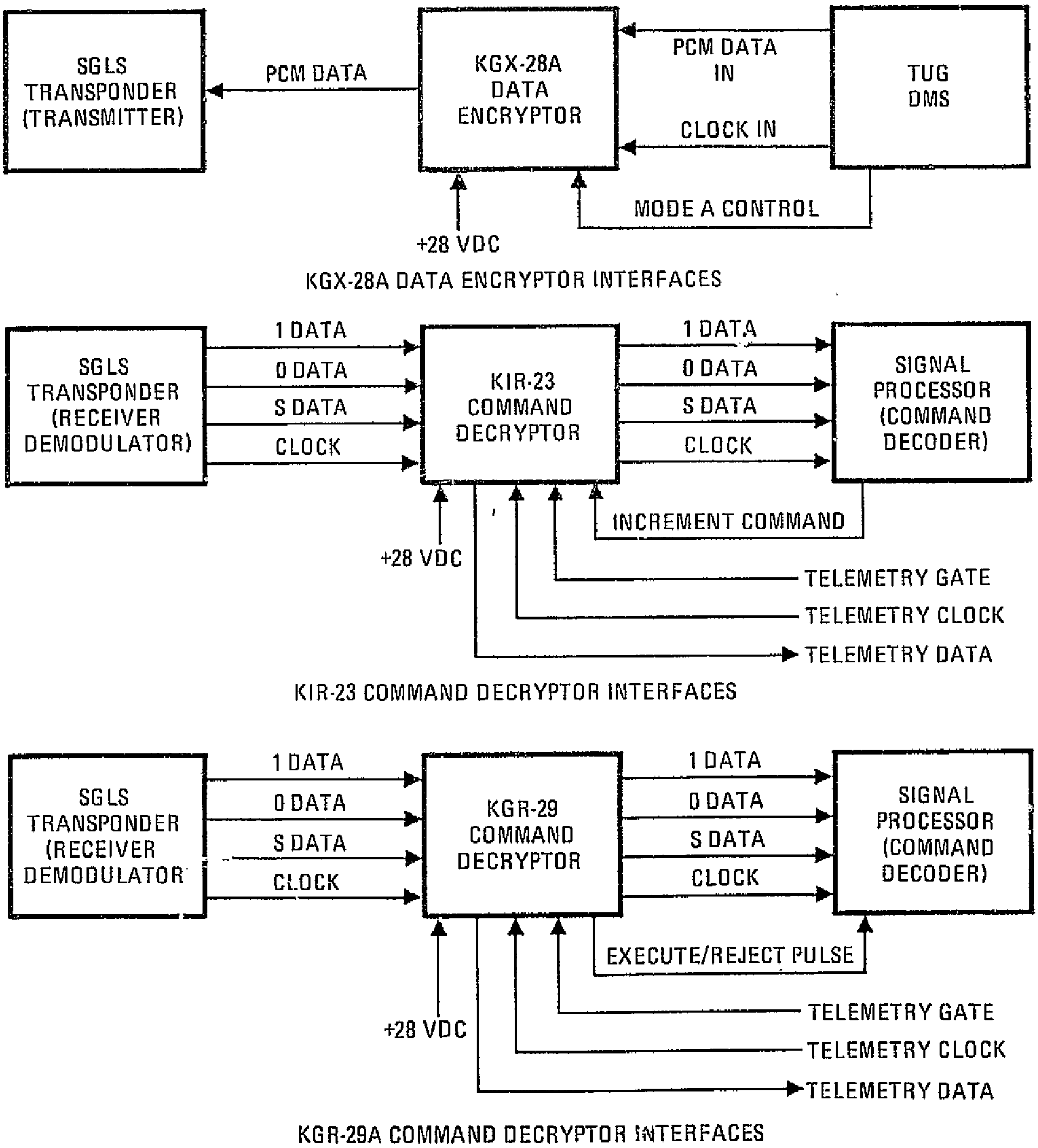


Figure 5.2-3. Cryptographic Equipment Electrical Interfaces

Compromising emanations (referred to by the short term TEMPEST) can be controlled by a combination of the following:

a. Containment of the red sources.

b. Isolation of the transmitter from TEMPEST sources.

c. Isolation/shielding of red and black lines.

d. Isolation of the power bus from red processors.

Basically two different approaches can be considered for implementing the communication links in Tug hardware. One approach is a single vehicle hardware configuration that can be flown on most missions without major modification other than in software. The appropriate data path for the mission would be determined by the stored programs. The initial task would be greater to provide a design that assures compatible interfaces between a larger number of units. Since there is greater opportunity for either HIJACK or NONSTOP originated emanations that would compromise DOD secure links, the design task is more demanding in this respect.

The second approach is to alter the hardware setup to provide only NASA links, DOD links, or DOD secure links depending on the mission requirement. The hardware configuration would be accomplished by installing required units, removing excess units, and if necessary, installing dummy packages, interface units, or jumper harnesses in vacant locations.

Based on the relative complexity of protecting the cryptographic devices and keying material, the second approach involving removal of the devices for clear missions has been tentatively selected.

5.2.1.5 Ground Support System Requirements Analysis. Each of the candidate security systems has a compliment of ground support equipment that is supplied GFE with the spaceborne hardware. Here is a summary of these equipments and their use:

KI-23 System — The ground support equipment for the KI-23 system consists of:

KIT-23	Command Security Transmitter
KIX-23	Manual Control and Test Unit
KIP-23	Power Supply

The units install in a standard 19 inch (48.2 cm) rack console and require about 37 inches of panel height. The units operate from 115 Vac, 60 Hz.

KG-29 System — The ground support equipment for the KG-29 system consists of:

KGT-29	Ground Operational Encryptor
KGR-7	Vehicle Simulator
KT-8	Maintenance Test Set

The units install in a standard 19 inch (48.2 cm) rack either directly or with an adaptor mounting panel. The units operate from 115 Vac, 60 Hz.

KG-28 System — The ground support equipment for the KG-28 system consists of:

KGR-28	Receive Data Security Equipment
ST-19	Test Set
KGT-7	Transmit Data Security Equipment (Vehicle Simulator)

The units install in a standard 19 inch (48.2 cm) rack by means of adaptor mounting panels. The units are powered from +4.3 Vdc and +28 Vdc.

Facilities — The facility requirements for communications security equipment are:

a. Physical security for the cryptographic hardware, support equipment, and coding data. This may involve controlled access or in the case of the flight hardware installed on the Tug could consist of physically covering the device and posting a guard to ensure that unauthorized personnel do not gain access to the device. The work area must meet the requirements of a controlled area as stated in Paragraphs 21 and 22 of the COMSEC Supplement to the Industrial Security Manual.

b. A TEMPEST test facility for vehicle qualification and acceptance test operations. The TEMPEST test facility will require approximately 100 dB of isolation over a broad frequency range to perform NONSTOP and HIJACK tests.

c. An acceptance test facility for the communication system operated on the Tug or separately. Since test authenticate codes and simulated data will be employed, the test facility requirements are no more stringent than those required for physical security of the equipment.

d. A launch site test and prelaunch operation facility. Launch site tests can be performed with test authenticate codes and simulated data for the cryptographic verification sequence. The bulk of the Tug testing including all of the LPS tests can be performed in cryptographic bypass mode. Prelaunch tests at Complex 39 will utilize the DOD Shuttle system security interface. Tug mission data can be placed on board the Orbiter as a classified magnetic tape and loaded into the Tug DMS through the Orbiter interface.

5.2.1.6 Security Implementation Cost Analysis. The cost analysis for the several aspects of communication security implementation is based on rough order of magnitude estimates that are used for trade-off purposes. The cost figures are not intended to be used for contractual purposes.

Hardware Cost Analysis — The implementation cost estimates for secure command and data links are listed in Table 5.2-6. The command link costs are dependent on the selected system; therefore, both candidate systems are included in Table 5.2-6. A larger proportion of some of the cost elements in Table 5.2-6 is assigned to the command system since the command link has a high probability of requiring encryption, and a majority of the cost exists whether one or both links are secured.

Table 5.2-6. Cryptographic Implementation Cost

Cost Element	Command System				Data System	
	KI-23		KG-29		KG-28	
	NRE	REC	NRE	REC	NRE	REC
Program Management	$75K	20K	75K	20K	40K	10K
COMSEC Analysis & Predesign	40K	-	50K	-	25K	-
COMSEC Design	150K	-	200K	-	100K	-
Procurement*	-	240K	-	100K	-	100K
Manufacturing & Test	75K	40K	100K	40K	50K	25K
Prelaunch Support	10K	40K	10K	40K	10K	25K
Total	350K	340K	435K	200K	225K	160K

*Includes the GFE cost of the cryptographic devices supplied by the DVEC office of SAMSO.

Facility Cost Analysis — The three facility requirements associated with the COMSEC equipment are:

a. Physical security for the spaceborne equipment separately and while installed on the Tug.

b. Physical security for the COMSEC ground equipment.

c. Test facility for TEMPEST testing.

These facilities may be configured separately, or in combination. As an example the test equipment may be installed in the vehicle test location.

The Tug manufacturing and test facility will require a small differential for controlled access. The modification will involve establishing controlled access to the dock either with a cypher lock or by posting a guard at the entrance. In either case the addition of walls will be required to control access and limit visibility. RF security will not be required because simulated data will be used for the tests.

TEMPTEST testing requires use of a well shielded room (approximately 100 dB) large enough to accommodate the Tug. A NONSTOP test that involves only high level signals can be performed on the total vehicle in the dock area. The estimated facility costs are:

a.	A cost for physical and visual security	\$20 K
b.	Construction of test equipment room	\$20 K
c.	Construction of TEMPEST test facility	\$100 K

5.2.2 CONCLUSIONS

5.2.2.1 Security Requirements. As stated in Section 5.2.2, a secure command link will be required for the DOD missions of the Tug to guard against spoofing and dissemination of guidance data.

The case for a secure telemetry link is less clear. Other than the possibility of revealing mission status or the vehicle targeting parameters, the Tug telemetry data does not contain information that would justify encryption of the link. Since it is not possible at this time to assess the impact of clear text telemetry on specific mission security and the resultant probability of obtaining a waiver, the Tug baseline design should provide for encryption of telemetry and TV data.

Several of the alternative techniques (versus a cryptographic system) considered show promise of application to the Tug mission and should be studied in depth to verify their suitable. Pending further stud , cryptographic devices are thus recommended for the Tug DOD missions.

5.2.2.2 Baseline Configuration. The Tug baseline communications subsystem configuration for the DOD missions includes both command and telemetry link encryption. Telemetry link and TV link security will be accomplished with the KG-28 system.

Command link cryptographic equipment selection is discussed in the following paragraphs.

Command System Selection — The two command security systems considered for the Tug-baseline are the KI-23 and KG-29. The KI-23 is smaller, lighter, and uses less power than the KG-29. The KI-23 is limited to a 20 bit command message while the KG-29 can process a 42 bit message in the authenticate mode. In addition the KG-29 can process messages at a significantly faster rate than the KI-23, which may be important for computer memory updating operations that involve a large number of words.

The KG-29 system is recommended for the Tug baseline because of its greater flexibility, operating speed, and because of the command word format, which is compatible with the Tug baseline computer word length of 32 bits.

Baseline Security System Description — The baseline communication system for the DOD missions, including the cryptographic devices, is shown in Figure 5.2-4. The cryptographic bypass capability for the command link is used in the test or prelaunch mode but not in flight. The bypass is controlled by coaxial switches whose fail-safe position is in the cryptographic mode. The bypass mode for the telemetry link may be selected by command for ground operations or during flight. For both systems, the ends of the bypass circuit will be shorted to ground when the cryptographic devices are in the cypher mode to prevent the presence of red data on the cypher line.

Alternate Configuration — A potential alternate configuration for the DOD missions is a system with an encrypted command link and a clear text telemetry link. This configuration may be practical for all of the DOD missions if a thorough analysis of the data establishes that security is not required or for a portion of the missions if the security requirements can be isolated to particular payloads and payload data (C&W). In the first case both nonrecurring and recurring costs would be saved. For the latter case, only the recurring costs would be saved for the missions that do not require a secure data link.

An important argument against operating a portion of the DOD missions with a clear telemetry link is that the presence of a high security payload would be pointed up by the existence of an encrypted link.

5.2.3 RECOMMENDATIONS. It is recommended that the following trade studies and analyses be performed to more completely identify the Tug secure communications system requirements.

a. Analyze the security classification of the DOD payloads to accurately determine the cost savings in operating the telemetry and TV links unsecured.

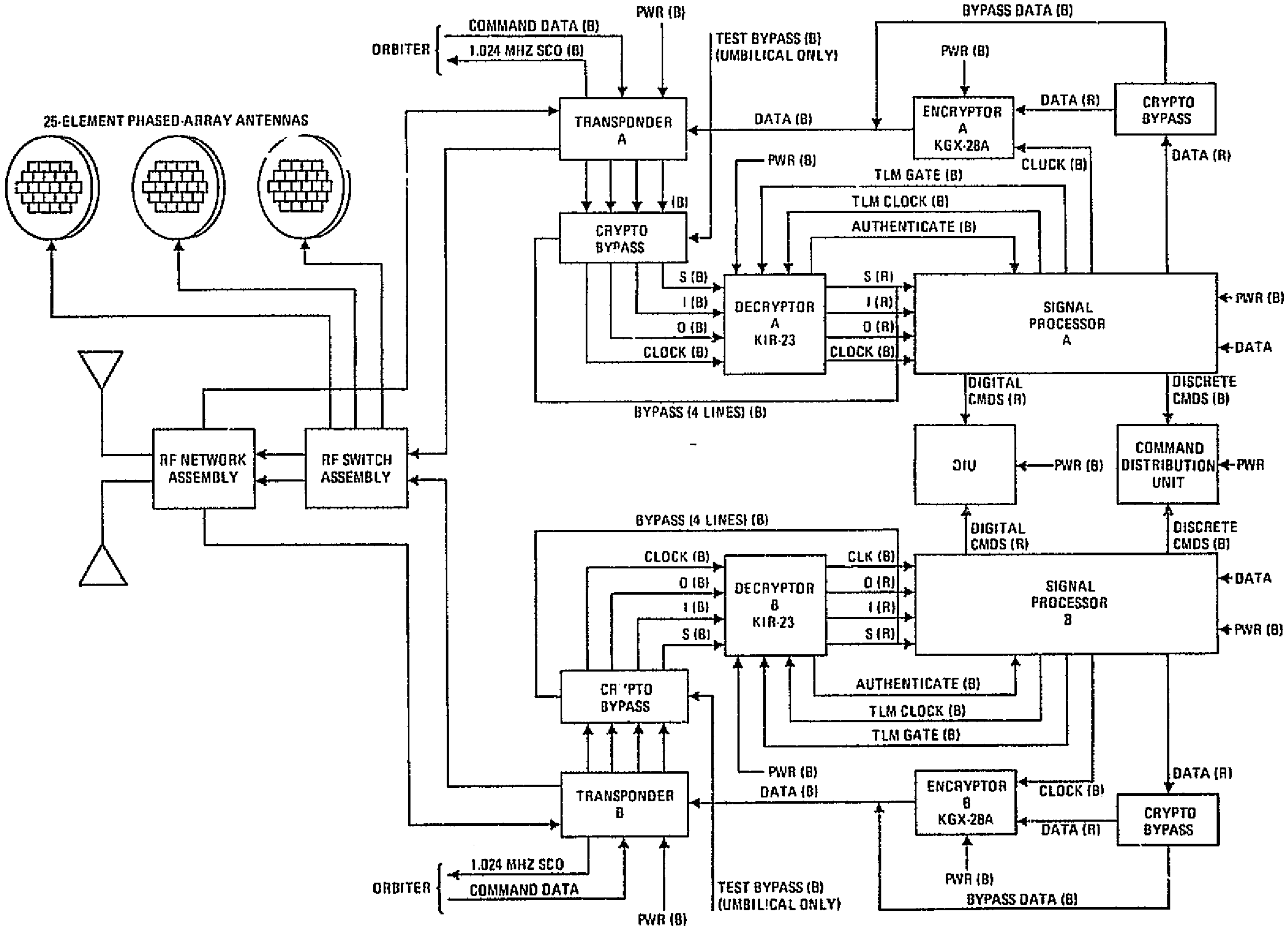


Figure 5.2-4. Secure Communications Block Diagram

b. Perform a detailed avionics configuration trade study based on the NASA and DOD nonsecure mission requirements versus those of the secure DOD missions.

c. Analyze in depth the alternatives to cryptographic devices such as computer algorithms, narrow beam antennas, and a 60 GHz communications satellite link.

d. Obtain the 1978 projection for cryptographic hardware characteristics.

e. Coordinate with the Orbiter and launch facility programs on the cryptographic and TEMPEST interface requirements.

5.2.4 BIBLIOGRAPHY

CASD-NAS75-012	Space Tug Avionics Definition Study, General Dynamics Convair Report
CSESD-1	Communications Security Equipment System Document, TSEC/KG-28
CSESD-2	Communications Security Equipment System Document, TSEC/KI-23
CSESD-7	Communications Security Equipment System Document, TSEC/KG-29
MIL HDBK-232	Military Standardization Handbook Red/Black Engineering - Installation Guidelines
NACSEM 5100	Compromising Emanations Laboratory Test Standard, Electromagnetics
NACSEM 5200	Compromising Emanations Design Handbook

5.3 TUG SELF CHECKOUT CAPABILITY

A sensitivity analysis was conducted to determine effects on the Orbiter/Tug avionics support equipment (and associated interfaces) as a function of Tug self-checkout capability.

In this sensitivity analysis, effects of implementing a higher and lower level of onboard checkout capability (with respect to the baseline Tug) were examined. Outputs include identification of hardware and software changes to baseline Orbiter/Tug support equipment and impact of changes on Shuttle interface requirements. For hardware items and physical interfaces, these changes are expressed in terms of data processing requirements, input/output equipment, and size, weight, and power requirements.

Software effects are identified in terms of program complexity (number, size, data storage requirements, and real-time requirements).

Three levels of self test were analyzed to determine the best self-test method for Tug using low cost, low risk, and low complexity as the driving decision criteria. These levels of self test are indicated in Figure 5.3-1 and discussed herein.

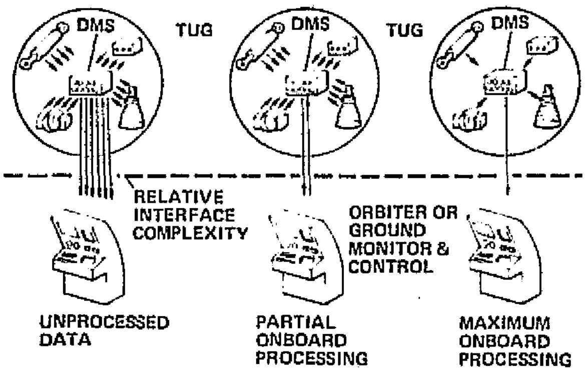


Figure 5.3-1. Tug Self Checkout Concepts

5.3.1 LOW SELF TEST. Low self test is basically the method used for launch vehicles such as the D-1 Centaur (mid 60's technology). It was used because computers were large, heavy, and expensive (LSI had not yet come into its own — not to mention microprocessors), which forced checkout capabilities to be "stuffed" into one ground computer with costly programming and interfacing required. In this method an operator at a ground console (usually including a CRT and keyboard) would systematically execute ground and vehicle software programs that would stimulate a vehicle test function and monitor the results via the vehicle TLM system. These test results would then be displayed to the operator via a CRT or line printer.

This concept created a complex of interleaved programs and interface logic that was difficult to manage and control. For example, the vent and pressurization engineer was forever concerned that the guidance software change might adversely affect the computer controlled vent and pressurization software system. One of the major problems with this type of system is that the vehicle/ground interface must operate at relatively high speed. This occurs due to the real-time environment of vehicle test and the large amount of data transfer between vehicle and ground. This real-time, high-speed environment increases the complexity of both the hardware and software involved, which in turn results in cost integration and operational) and schedule penalties. The advantages of this testing method include: 1) the ground based nature of the automated test equipment (ATE) involved allows the system to expand to meet almost any level of testing required independently of power requirements, vehicle weight, and vehicle DMS memory size, 2) this concept causes the least weight and integration impact to the vehicle since little or no equipment must be added to the vehicle logic, and 3) the risk is low since the technology exists, and much experience has been gained through the use of this testing technique on current launch vehicle programs.

The limitations of Tug low self test are greatest during the flight phases of operation as shown in Table 5.3-1.

Table 5.3-1. Tug Low Self-Checkout Capability Characteristics

Operational Characteristics	Impact
Checkout programs loaded via uplink from Orbiter or ground	Increase in Orbiter computer support requirement. Possible dependence on availability of ground coverage
Minimal fault isolation	Less confidence in vehicle
Greater Orbiter crew support required	Increased crew training
Checkout affected by detached operation	Dependent on availability of ground communication coverage. Checkout and operations speed slow down due to mechanics of ground/Tug RF communication links

5.3.2 PARTIAL SELF TEST. The partial self-test concept as depicted in the Tug baseline indicates that the computer complex should include self-test microprocessors for those systems that are localized and keep the centralized testing concept for those systems that are dispersed all over the Tug in many small parts. Thus, for Tug operations, microprocessors or built-in-test-equipment (BITE) might be integrated into the logic design of complex Tug systems such as the GN&C system, but would not be incorporated into dispersed Tug systems such as the electrical power distribution system. In the power system, individual power circuit status can be monitored via sensors and processed via either Tug or Orbiter checkout or validation software. Some operational characteristics associated with the partial self-test approach are shown in Table 5.3-2.

5.3.3 TOTAL SELF TEST. Total self-test concept involves using microprocessors throughout the Tug vehicle no matter how simple the hardware to be tested. This concept is predicated on large scale integrator (LSI) growing to the point where microprocessors are small, fast, cheap, and easy to design for special purpose aerospace applications. This is already the case for commercial applications such as calculators, and in aerospace the B-1 bomber avionics system design very closely approaches this concept. In this concept, the real-time problems associated with a complex payload to Orbiter/LPS interface would be almost totally eliminated since only status and diagnostic data would be conveyed from Tug to the test operator. In its advanced form, Tug self testing would occur continuously during flight or selected ground operations and status outputs would be made available only: 1) where specifically requested, 2) automatically at selected mission times, or 3) in the event of a failure and subsequent switching to redundant systems or components.

Table 5.3-2. Partial Self-test Characteristics Using BITE

Operational Characteristics	Impact
BITE provides status of line replaceable unit (LRU) to Tug/Orbiter DMS	Less Orbiter/LPS software required to obtain same level of data. Interface real-time requirement less severe
Typical readiness confidence of 95%	Results in higher level of vehicle confidence with lower ground/Orbiter involvement
Typical fault isolation to one LRU 90% of time	Aids problem isolation during both flight and ground operations
Software must be added to Tug DMS to perform test and checkout functions	Increase of 5 K words to Tug memory
Allows automatic switching of redundant components	Involvement with Tug redundancy management concepts and implementation philosophy

The results of a trade study to determine other Tug/Orbiter/ground impacts resulting from these three checkout methods is shown in Table 5.3-3. This data indicates that significant program cost and performance benefits can be gained by both partial and total self-checkout concepts (with respect to low self-test). Tug to Orbiter/ground operational interface complexity, and Tug power requirements, should both be reduced (due to decrease in Tug and intra-Tug physical interface complexity).

Table 5.3-3. Tug Checkout Sensitivity Evaluation Results

EVALUATION CRITERIA		LOW SELF TEST	PARTIAL SELF TEST	TOTAL SELF TEST	AVIONICS SYSTEM REFERENCE
WEIGHT LB (kg)		• 0	^ • 20(9)	^ • 40'18)	903(410)
RISK		5	.6	.7	1
SPEED REQR. (KOPS)	CHECKOUT	190	13	5	N/A
	TUG	65	35	12	400
MEMORY (WORDS)	CHECKOUT	60400	28K	1050	N/A
	TUG	3000	8K	5520	48K
REAL TIME		FAST	SLOW	SLOW	FAST
INTERFACE COMPLEXITY	WIRES/LRU	15	7	BUS INPUT	N/A
POWER (WATTS)		180	76	35	1,485
OPERATIONAL COMPLEXITY		HIGH	MED	LOW	N/A
COST ($M)		+10.4	0	+.541	100

For Tug operations, however, the partial self-test concept is recommended due to the lower cost, weight penalty, and program risk incurred. It is further recommended that BITE logic be incorporated for the Tug DMS, engine control electronics, signal conditioners, portions of the GN&C system, the rendezvous and docking system, and for the Tug fuel cells. Other Tug avionic and nonavionic systems would be monitored via remote sensors that supply system health data to the Tug DMS for

analysis. Tug system health information would then be provided to the Orbiter and ground via the Tug telemetry downlinks in the form of Tug systems status words. Table 5.3-4 indicates typical status work information communicated in this manner; Orbiter or ground support software programs would compare (in non-real-time) this data with expected system status data tables to determine the existence and nature of problems.

To summarize, the recommended approach is to employ partial self-checkout techniques at least to the extent that the Orbiter software is required only to monitor data and is not required to perform checkout operations as such.

Table 5.3-4. Typical Tug TLM Status Word/Bits

Sun tracker check	Buffer formatter check
Rate gyro check	Tape recorder check
Control electronics check	Instrumentation checks
Communications check	GN&C checks
AESPA transmitter/receiver check	Gyro checks
TV systems check	Accelerometer checks
Phase control/receiver check	Rendezvous and docking
Electrical power system	Scanning laser radar
Fuel cell checks	Docking mechanism
Battery check	Propulsion/mechanical check
Aft power distributor	Engine check
Forward power distributor	Pneumatic check
DMS check	Hydraulic check
CPU check	Attitude propulsion checks
CIU check	Thrust vector control
DIU check	Vent and pressurization system
IOP check	Propellants/structures
Main memory check	Interface checks

C-7

5.4 FLUID SERVICES

Future changes in Shuttle/Tug operations may revise optimization results or make alternative fluid service/interface concepts and techniques rejected in Task 2 (Section 4.4) more attractive for the baseline Tug. In addition, future Tug design changes (e.g., the type of propellant used) could have major effects on service line/interface requirements. A change from cryogenic to storable main propellants, for example, would affect all main propulsion services to some degree. Some services may be required for one propellant combination and not the other, and where similar services are required (e.g., fill and drain, vent), operational procedures, optimum diameter, insulation requirements, and environment (pressures, temperatures, corrosiveness, etc.) may be widely different.

This task investigated sensitivities for changes, alternatives, and variations in Tug fluid systems design and operation. Five subsystem areas: main propulsion, leakage vent, auxiliary propulsion, pressurization, and fuel cells were included in this evaluation. Table 5.4-1 indicates the alternative services investigated within each subsystem, and summarizes the interface effects.

The main Tug change considered was a change from cryogenic to storable main propellants, which simplifies service line requirements (i.e., no topping line or line insulation requirements) as shown, but which introduces potential abort dump corrosion and contamination problems, which were not evaluated in this study. The interface revisions associated with a change in main propellants are major, and they require detailed analyses similar to those accomplished for cryogenic fluid services in Section 4.4. Such analyses were beyond the scope of this task.

Sensitivity of the cryogenic Tug services to revised abort requirements is covered in Section 5.6.

External leakage vent capability was investigated for storable propellants. It was concluded that provision of these overboard purge vents for propellant tank doors and service line joints/disconnects would probably be desirable. Line sizes for this interface would not change appreciably, 0.5 inch (1.27 cm) diameter, but materials revisions would be necessary to withstand the corrosive propellants. Line heaters and safing devices might be necessary to meet environmental requirements.

Investigation of interface effects due to changes in the auxiliary propulsion and pressurization subsystems resulted in insignificant sensitivities. The only potential interface impact is caused by a nonintegrated cryogenic auxiliary propulsion system. Separate vacuum jacketed LH_2 and LO_2 fill and drain lines would be required with this operationally undesirable option.

The type of fuel cell used by Tug was found to have a significant interface impact. Interface considerations were a major factor in selection of thermally integrated

Table 5.4-1. Tug Fluid Services Sensitivity

Subsystem	Alternative	Service	Effect
Main Propellant	Storables instead of Cryo	• Fill, Drain & Abort Dump	• Approx. same dia line for N_2O_4 • Smaller line for MMH • Vacuum jacket not required • No topping line required
		• Vent/Relief	• Smaller lines • No zero-g vent
		• Load in PCR or Earlier	• Eliminates all services except dump
	Revised Dump Time Constraint	• Abort Dump	• Potential line size change
	Revised Loading Timelines	• Fill & Drain -	• No effect since abort dump sizes lines
Leakage Vent	Storables instead of Cyro	• Leakage Membrane, Seals & Discon. Panel Vent	• Dispose of liquids instead of gases • Potential evaporative freezing problems • Potential leak, residuals hazards upon return
Auxiliary Propulsion	Biprop instead of N_2H_4	• Fill & Drain • Vent Relief	• Accomplish in PCR, no added interfaces • Added interface, approx. 0.5 in. (1.27 cm) dia.
	Cryo instead of N_2O_4	• Fill, Drain & Dump	• No added I/F if main tank propellants used • Two added I/F if separate storage used
		• Vent/Relief	• None - combined w/main tank vents
Pressurization	GN_2 instead of Helium	• Charge & Vent	• No significant change
Fuel Cells	Supercritical instead of Main Tank Propellants	• Fill, Drain & Dump • Vent • Ground Cooling	• Adds two interfaces • None - combine w/main tank vents • Adds two interfaces

lightweight fuel cells for the recommended Tug configuration. Figure 5.4-1 depicts interfaces for the modified Orbiter and integrated lightweight fuel cells. Since the lightweight cell is designed to operate with low-pressure, propellant grade reactants, it draws LH_2 and LO_2 directly from the Tug propellant tanks and has no special fluid interface requirements. Conversely, the modified Orbiter fuel cell needs high-purity, saturated reactants that require separate storage and interface (vacuum jacketed LH_2 and LO_2 fill and drain) equipment. Additionally, a prelaunch ground water coolant loop is needed with the non-thermally integrated fuel cell to remove waste heat, resulting in two more Orbiter interfaces. Both fuel cell types share vent and purge functions with Tug main propellants. Therefore, the modified Orbiter cell requires four dedicated umbilicals compared with none for the integrated lightweight fuel cell design. Table 5.4-2 includes a comparison of interface weight associated with these two fuel cell systems.

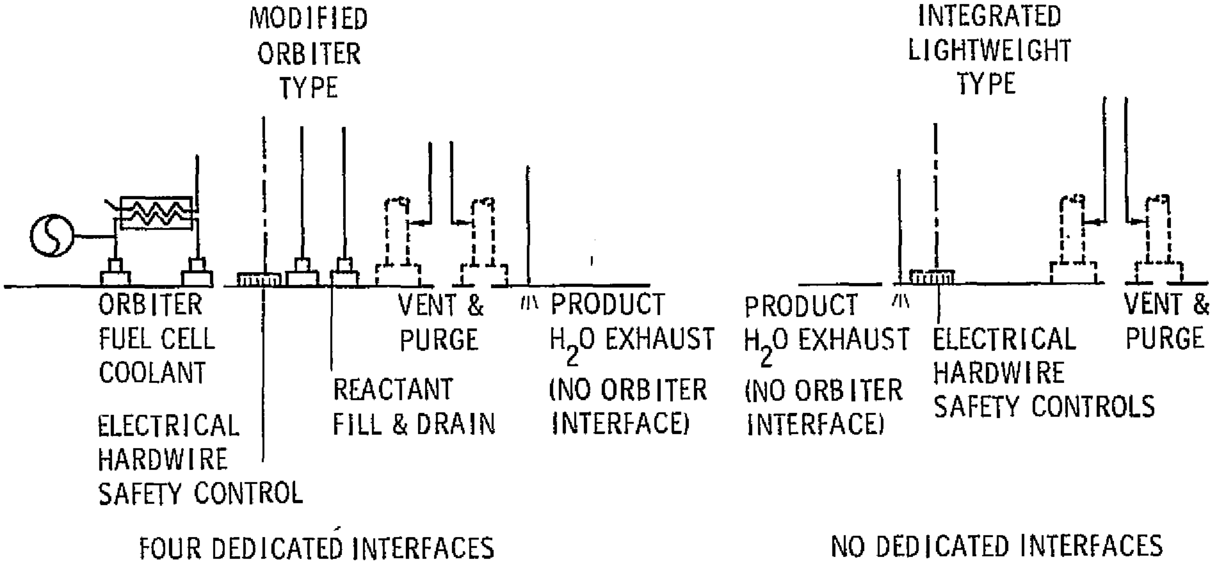


Figure 5.4-1. Fuel Cell Fluid Interface Sensitivity

Table 5.4-2. Fuel Interface Weight Comparison

Equipment	Modified Orbiter (Dedicated Reactant Supply System)		Integrated Lightweight (Reactants from Main Propellant Tanks)	
	lb	(kg)	lb	(kg)
Feed Lines and Disconnects	25.0	(11.3)	8.0	(3.6)
Purge Vent and Safing	4.8	(2.2)	3.0	(1.4)
Redundancy Hardware	9.0	(4.1)	-	-
Total	38.8	(17.6)	11.0	(5.0)

5.5 TUG PAYLOAD SERVICES

Payload services may be accommodated with alternative routings as indicated in Figure 5.5-1. The payload Orbiter services accommodations trade, performed in Section 3, recommended discriminatory use of all these routing options except spacecraft direct to Orbiter. Service accommodation recommendations from this trade are presented in Table 5.5-1.

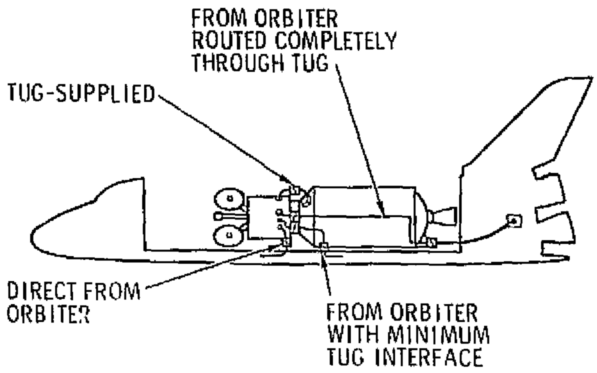


Figure 5.5-1. Orbiter/Payload Interface Options

From the data in this table it is obvious that the Tug/Orbiter interface is affected by the payload service requirements imposed on the Orbiter either directly or through the Tug. This sensitivity task investigates the impact on Tug/Orbiter interface requirements of baseline Tug and payload changes that affect the payload/Orbiter interface requirements. Two types of baseline Tug changes were considered:

a. Changes affecting payload/Orbiter requirements accommodated through the Tug.

b. Changes affecting payload services provided by the Tug.

Changes of the first type affect the number and type of payload/Orbiter services that can be routed through the Tug. An example is a Tug diameter change that precludes routing a payload propellant line along the Tug. This results in changes in the umbilical panel and fluid raceway requirements.

Tug and payload changes that affect payload services provided by the Tug, while it is in the Orbiter, impact the Tug/Orbiter interface since they change the payload/Orbiter interface requirements. For example, a change in the Tug power available or needed for payloads may affect the power requirements that the Orbiter must supply to the payload. If the Tug can internally supply all payload power requirements, an active electrical power interface between payload and Orbiter is eliminated. This would change umbilical and raceway requirements.

Obviously sensitivities addressed in this investigation must be evaluated in reference to the work accomplished in Section 3 and summarized in Table 5.5-1. Both fluid and electrical service sensitivities were evaluated. Sensitivities for seven payload fluid services and 14 possible changes were evaluated as summarized in Table 5.5-2. No revisions to the previously recommended payload/Orbiter fluid service interfaces of Table 5.5-1 resulted from these analyses.

Table 5.5-1. Recommended Payload Service Accommodations from Section 3

Payload Function	Service Level	Accommodation	Interface	
			Tug	Orbiter
Prop. F&D	~0.5 in. (1.27 cm) dia each prop.	Remote	No	No
Abort Dump	< 500 lb (227 kg) ≫ 500 lb (227 kg)	Self contain Overboard dump kit	No No*	No Yes
Vent	~0.5 in. (1.27 cm) dia N_2H_4 prop. ~0.5 in. (1.27 cm) dia each other prop.	Integrate w/Tug RCS vent Overboard vent kit	Yes No*	Existing Yes
Press Fill	~0.25 in. (0.63 cm) dia	Remote	No	No
Vent	~0.25 in. (0.63 cm) dia	Into cargo bay	No	No
Battery Vent	~0.5 in. (1.27 cm) dia	Integrate w/Tug bat. vent or self contain	Yes	Existing
LHe F&D	~1.0 in. dia (2.54 cm)	Direct to 835 T-4 panel	No*	Yes
Vent	~1.0 in. dia (2.54 cm)	Into cargo bay	No	No
RTG Cooling	~0.5 in. (1.27 cm) dia H_2O inlet/outlet ~3.0 in. (7.62 cm) dia steam vent	Thermal control unit (water boiler) kit	No No	Yes Yes
Shroud Repress	No known	Payload autonomous	No	No
Conditioning	~3.0 in. (7.62 cm) dia class < 5000 GN_2	Direct to Orbiter	No*	Yes
Communication	2 Kbs up 51 Kbs down	Via Tug avionics	Yes	Yes
Caution & Warning	35 signals	Through Tug	Yes	Yes
Data Processing	Storage & Computation	Orbiter supplied	No	Yes
Power	700 W ground & on-orbit 600 W ascent	Orbiter 695 panel via Tug From Tug fuel cell	Yes Yes	Yes No

*Assumes forward umbilical panel

Table 5.5-2. Payload Fluid Service Sensitivities

P/L Service Accommodated	Possible Change to Service	Effect
Propellant Fill & Drain	Propellant Quantity Increase	Increased payload penalty for designing to crash loads full or incorporation of abort dump capability
	On Pad Fill & Drain	Adds 4 active interfaces and 21 lb (9.5 kg) per fluid accommodated
	Abort Dump Required	Same hardware as fill & drain except for PL-01-A (Biprops) where larger lines (1 in. (2.54 cm)) & increased weight penalty (+38 lb (17 kg)/fluid) result
Propellant Vent	Vent Not Required	Eliminates 6 interfaces & saves approx. 42 lb (19 kg) for biprop. Eliminates P/L to Tug I/F & saves approx. 10 lb (4.5 kg) for N_2H_4
Pressurant Fill	Pressure Quantity Increase	Negligible
	On Pad Fill	Adds 3 active interfaces and 20 lb (9 kg)
	Vent into Cargo Bay Not Allowed	Same as on pad fill
Cryo Fill, Drain & Vent	Quantity Increase	Same as propellant quantity increase
	Fill/Top Until T-0	Slight increase in line diameter adds 1 active interface & approx. 40 lb (18 kg)
	Vent into Cargo Bay not Allowed	Adds 4 active interfaces & approx. 40 lb (18 kg)
RTG Cooling	Increased Heat Load	Increases water required for heat sink & water boiler (approx. 12 lb (5.4 kg) H_2O/hr/1000 Btu)
	Cooling Kit Fwd in Bay Instead of Aft	Adds 60 ft (18 m) of steam vent line, increases dia to approx. 4 in. (10 cm), adds approx. 70 lb (32 kg)

Table 5.5-2. Payload Fluid Service Sensitivities (Contd)

P/L Service Accommodated	Possible Change to Service	Effect
Shroud Purge & Repressurization	Eliminate Shroud	Increases cargo bay cleanliness level to ≤ 5000 (probably not practical) Eliminates 3 active interfaces, saves approx. 70 lb (32 kg)
Battery Vent	Eliminate Vent Requirements	Saves 2 active interfaces and approx. 10 lb (4.5 kg)

Electrical service sensitivities are summarized in Table 5.5-3. Effects for four payload services and eight possible changes are included. As was the case for fluids, no revisions to those avionics services recommendations in Table 5.5-1 were made.

In addition to the effects of possible changes listed in Tables 5.5-2 and 5.5-3, one general conclusion can be reached from the Tug payload services sensitivity investigation: a fairly direct payload-to-Orbiter (standardized by routing through the forward end of Tug) umbilical connection serves to desensitize both Tug and its payload from changes in payload services. When the Space Transportation System becomes operational, scientific and exploitive payloads with exotic service needs will want to take advantage of its unique capability. If a standard method for accommodating these services exists (forward umbilical panel) the impact of accepting such payloads will be minimized.

5.6 ALTERNATIVE ABORT MODES

Shuttle performance and Orbiter/Tug interface provisions are affected to a major degree both by 1) changes in Orbiter abort modes and by 2) selection between alternative design approaches for implementing given abort requirements. As an example of 1) elimination of the RTLS abort mode would eliminate rapid dump requirements and reduce service line interface weights for both Orbiter and Tug. As an example of 2) elimination of rapid LH_2 dump while retaining RTLS abort would reduce penalties associated with dump while adding penalties due to landing full of LH_2, including increased interface structural loads, landing weights, and post-landing operations complexity.

Tug impacts and Shuttle requirements effects for both alternative non-baseline abort modes and alternative abort implementation concepts have been identified. Data was

Table 5.5-3. Payload Electrical Service Sensitivities

P/L Service Accommodated	Possible Change to Service	Effect
Communication	Not Integrated with Tug Avionics	Minor Tug weight increase for added link 5 lb (2.3 kg)
		Simplifies Tug avionics (C&W impact)
	Data Rate Increase	No Tug effect — Orbiter transmission/receiving impact
	Hardwired Rather Than Multiplexed	Significant P/L weight penalty increase 165 lb (75 kg) if routed through Tug
		Minor Tug increase through forward panel
	Use of Optical Data Links	Significant weight reduction with added benefits of superior P/L to Orbiter isolation and immunity to EMC
Caution & Warning	Increased Quantity of Hardwired Signals	Tug weight increase 40 lb (18 kg)/35 functions
	Redundant Multiplexed Rather Than Hardwired	Tug weight saving 40 lb (18 kg)/35 functions
		C&W philosophy impact
Data Processing	Increased Requirements	No Tug effect — added Orbiter or payload supplied equipment capability
Power	Increased Ascent Requirements	Max of 2.4 kW available for P/L use (Tug capability 3.5 kW for 8 hrs at no penalty)
	Increased Ground & On-Orbit Requirements	Route large transmission line through forward umbilical from 695 panel small Tug wt penalty

developed in sufficient detail to allow Shuttle program assessment of Orbiter impacts in addition to evaluation of Tug/Orbiter interface sensitivities.

The full range of abort mode revisions and corresponding interface service, Tug, and Orbiter effects are summarized in Table 5.6-1. Some of these alternatives have been addressed in Section 4.4.2 (Orbital dump using Orbiter ACPS setting), and others have extremely low probabilities of Shuttle consideration. The three most important alternatives addressed in this abort sensitivity study are effects of: RTLS dump time sensitivity, progressive elimination of abort requirements, and elimination of Tug LH_2 abort dump.

Table 5.6-1. Alternative Abort Modes

Alternative	Probable interface/ service line effects	Probable Tug Effects	Orbiter Operations Effects	Comments
No Abort	Reduced service line diameters Eliminate four Orbiter controls Eliminate aft-facing dump ports	Reduced pressurization weight Reduced tank weights		
No RTLS Abort	Reduced service line diameters	Reduced pressurization weight Reduced task weights		
No RTLS LH_2 Dump (land with LH_2)	Reduced dump line diameter Increased structural loads	Reduced pressurization weight penalties Minor Tug structural weight penalties Horizontal vent/drain requirements	Increased landing weight Postlanding LH_2 disposal	Landing weight & cg within specification
No RTLS LH_2 or LO_2 Dump (land full)	Increased structural loads	Reduced pressurization weight penalties Major structural weight penalties Horizontal vent/drain requirements	Increased landing weight Revised Tug/P/L cg Postlanding LO_2 & LH_2 disposal	CG without payload currently unacceptable Landing weight above specification
No RTLS LH_2 or LO_2 Dump No Orbital LO_2 Dump	Reduced dump line dia. Eliminate 2 Orbiter controls	Further reduction in LO_2 dump line diameter	Same as above	Same as above
No RTLS or Orbital Dump of LO_2 or LH_2	Reduced dump line dia. Eliminate aft-facing dump ports Eliminate 4 Orbiter controls	Further reduction in LH_2 dump line diameter	Same as above	Same as above
Orbital dump at Zero-g	Eliminate aft-facing dump ports Eliminate 4 Orbiter controls	Advanced development of passive propellant control devices	None	
Orbital Dump Using ACPS Settling	Increase dump line dia. Eliminate aft-facing dump ports	Increased dump line dia.	Operate ACPS to near depletion	
Dump Time: 200 to 406 sec.	Dump line diameter variations	Variation in dump line diameters & pressurization system weight	None	

Design for Shuttle abort has significant impact on the design of Tug and its fluid service equipment. The following sections address the effect of variations in abort requirements and in methods of meeting baseline abort requirements.

5.6.1 DUMP TIME SENSITIVITY. For RTLS abort a minimum of 300 seconds of SSME powered time is available for propellant dump. This 300 second time was assumed as a design requirement for all analyses and trades of Section 4.4 (Task 2). Analyses were made in Task 3 to determine the sensitivity of dump line diameter, tank dump pressure, and deployment payload to variation in dump time from 200 to 500 seconds. Figures 5.6-1 and 5.6-2 give diameter requirements for a range of tank dump pressures. Figure 5.6-3 gives diameter requirements for the baseline Tug tanks pressures of 17.0 (11.7) and 18.0 psia (12.4 N/cm^2). Required diameters range from 5.8 (14.7) down to 3.6 in. (9.1 cm) for LH_2 and from 4.7 (11.9) down to 3.1 in. (7.4 cm) for LO_2. Figure 5.6-4 gives the corresponding sensitivity of payload for the deployment mission to dump times.

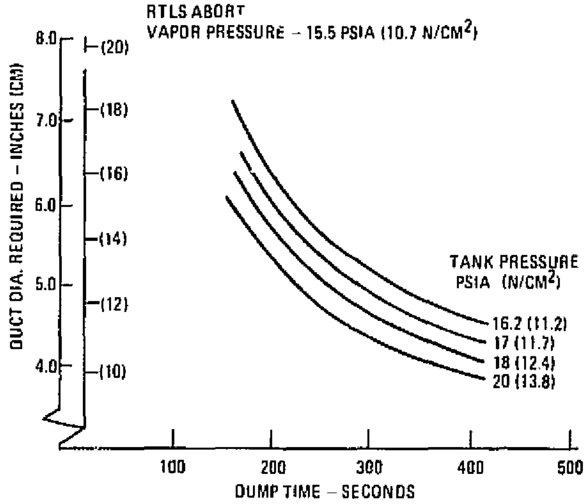


Figure 5.6-1. LH_2 Dump Line Diameter Requirement Versus Dump Time

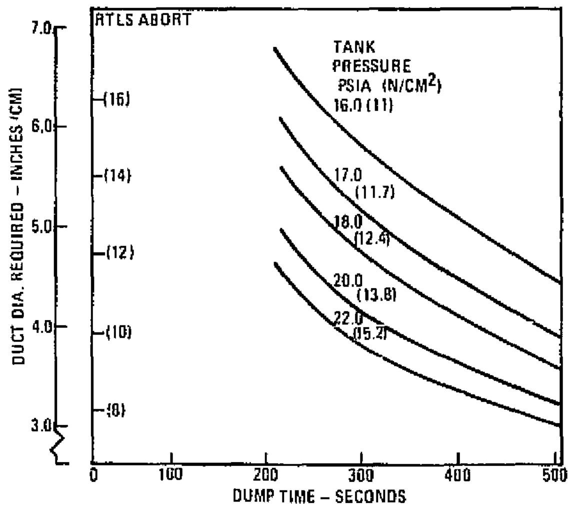


Figure 5.6-2. LO_2 Dump Line Diameter Requirements Versus Dump Time

5.6.2 ELIMINATION OF ABORT REQUIREMENTS. Requirements imposed on Tug for compatibility with current Orbiter abort operations result in substantial Tug performance penalties. This section summarizes analyses of the effects on payload for some alternative abort operations, as follows:

a. No Orbiter abort — The Tug and its support systems are not designed for Orbiter abort. No propellant dump or drain capability is needed after launch. The fill, drain, and topping lines are sized for prelaunch ground operations only. Sufficient helium is carried in the deployment adapter for repressurization of the propellant tank after normal recovery only.

b. No Orbiter RTLS Abort — No requirement to design the Tug for RTLS abort. Only low-g dump capability is pr vided for AOA, ATO,

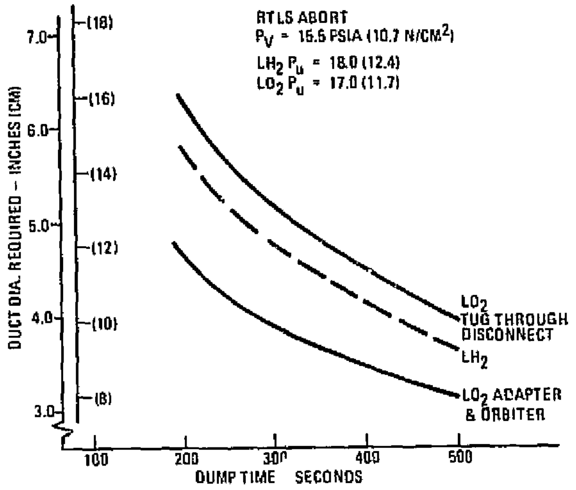


Figure 5.6-3. Dump Line Diameter Requirements Versus Dump Time

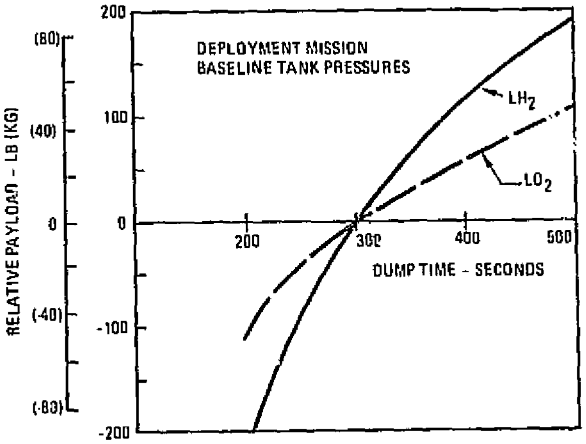


Figure 5.6-4. Payload Sensitivity to Dump Time

and AFO. This requires increasing the diameters of the fill and drain lines and pressurizing the LO_2 tank to 18.0 psia (12.4 N/cm^2). Helium requirement is increased 10 lb (4.5 kg).

c. No LH_2 Dump — The Orbiter aborts, but Tug LH_2 dump capability is not provided. The Tug lands full of LH_2 for all aborts and ground venting/draining capability is provided. LO_2 dump capability is provided for all aborts by further increasing LO_2 dump line diameter.

d. NO RTLS LH_2 Dump — The Orbiter aborts, but only low-g LH_2 dump is provided. The Orbiter lands full of LH_2 for RTLS abort and ground LH_2 venting/draining capability is provided. LH_2 fill and drain line is increased in diameter from 2.0 to 3.0 in. (5.08 to 7.62 cm) to provide the low-g dump capability.

Tug tank pressures, line diameters, and weights for the baseline and for the alternatives defined above are summarized in Table 5.6-2. Eliminating all abort requirements (no abort) improves payload for the deployment mission by 782 lb (355 kg). Most of the improvement (600 lb or 272 kg) can be obtained by eliminating the RTLS abort requirement (no RTLS abort), retaining the low-g dump capability only.

5.6.3 ELIMINATION OF TUG LH_2 ABORT DUMP. Data presented in Table 5.6-2 shows that elimination of LH_2 abort dump capability improves deployment payload by 429 lb (195 kg). This improvement results from weight savings due to reduction in fill and drain line diameter and reduction in helium pressurant requirements, in part offset by addition of equipment for post-landing venting and draining of LH_2. This payload improvement is gained at the expense of increased operational complexity and potential reduction in safety.

Table 5.6-2. Alternative Abort Modes Sensitivity

Item	Baseline	No Abort	No RTLS Abort	No LH_2 Dump	No RTLS LH_2 Dump
Nominal Abort Tank Pressure psia (N/cm^2)					
LH_2	18 (12.4)	-	15.5-10 (10.7-6.9)	-	15.5-10 (10.7-6.9)
LO_2	17 (11.7)	-	18 (12.4)	17 (11.7)	17 (11.7)
Fill, Drain, Dump Line Dia. inch (cm)					
LH_2	5.0 (12.7)	2.25 (5.7)	3.0 (7.6)	2.25 (5.7)	3.0 (7.6)
LO_2	5.4/3.8 (13.7/9.7)	2.25 (5.7)	2.75 (7.0)	5.4/3.8 (13.7/9.7)	5.4/3.8 (13.7/9.7)
Helium Pressurant Required lb (kg)	60 (27.2)	26 (11.8)	36 (16.3)	35 (15.9)	35 (15.9)
Dump System Wt lb (kg)					
Tug	Ref	-216 (-97.8)	-170 (-77)	-100 (-45)	-65 (-29)
Adapter/Orbiter	Ref	-585 (-265)	-418 (-2[illegible]0)	-447 (-203)	-495 (-225)
Payload increase lb (kg)					
Deploy	Ref	782 (355)	600 (272)	429 (195)	314 (142)
Retrieve	Ref	409 (186)	314 (142)	222 (101)	167 (76)

a. The Orbiter must land with the Tug full of LH_2, approximately 7400 lb (3360 kg). In event of a serious landing mishap, this could possibly be hazardous.

b. H_2 must be vented almost continuously after entry, as shown in Figure 5.6-5, and horizontal vent equipment (Section 4.4.2.4) is required. This figure shows LH_2 tank absolute pressure and venting rate histories for a complete RTLS abort without LH_2 dump. Tank pressure is allowed to rise to the assumed design limit of 20 psi (13.8 N/cm^2) differential during entry. A tank pressure blowdown to atmospheric pressure just before landing touchdown was assumed to determine the maximum vent free time available after landing. After lockup at atmospheric pressure, the tank pressure builds back up to the design limit (34.7 psia or 23.9 N/cm^2) within two minutes, where venting must be resumed at an average rate of slightly less than 400 lb/hr (181 kg/hr).

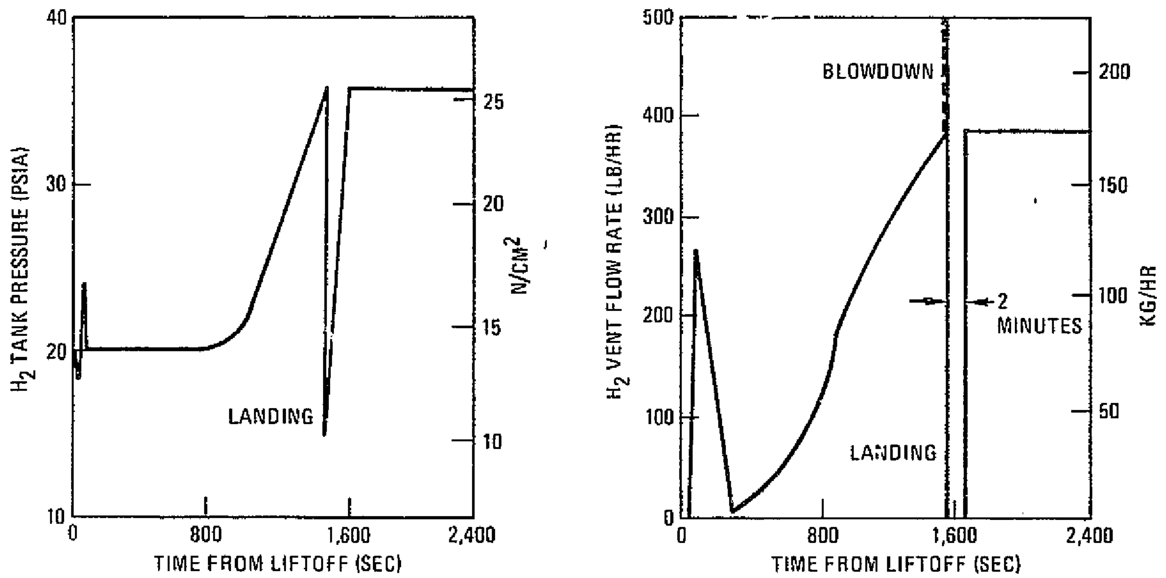


Figure 5.6-5. LH_2 Tank Pressure and Venting History, RTLS Abort Without LH_2 Dump

Figure 5.6-6 shows LH_2 tank pressure history after landing for an RTLS abort with LH_2 dump. Time available after atmospheric lockup varies from 26 to 36 minutes for maximum and minimum post-dump residuals respectively. Thus LH_2 dumping during RTLS abort allows a vent-free period of about 30 minutes after touchdown during which ground-safing equipment may be attached if required. The two minute maximum vent-free period permissible without dump would be inadequate for this purpose.

c. The LH_2 must be drained after landing. This requires addition of horizontal drain plumbing (as discussed in Section 4.4.2.4) and access to ground receiving

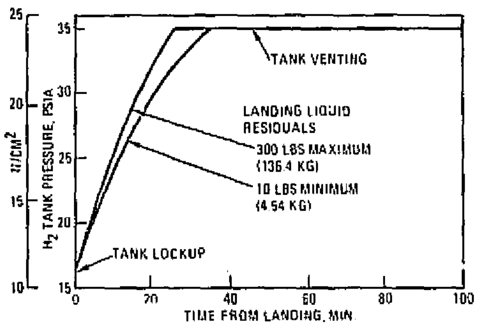


Figure 5.6-6. LH_2 Tank Pressure After Landing, RTLS Abort With LH_2 Dump

equipment for the LH_2 dumped. The ground drain plumbing would have to be attached to the T-0 panel during H_2 venting, as discussed above.

5.7 TUG LENGTH

Interface analyses performed in the preliminary screening and detailed assessment tasks considered a reference Tug with fixed length. The possible need to deploy very long spacecraft or perform high-energy retrieval missions may result in a Tug length different than the reference configuration. Tug length sensitivity was therefore investigated to determine interface requirements impact for lengths varying from 20 - 35 ft (6 - 10.5 m). Interface considerations resulting from these length changes include structural attachment and pivot locations, reaction magnitudes, and Tug center-of-gravity position.

The reference configurations and their pertinent characteristics are summarized in Figure 5.7-1. Mass properties for the deployment mission options assumed the reference spacecraft (Section 4.2.1.4) cantilevered from the Tug forward interface.

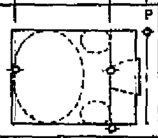
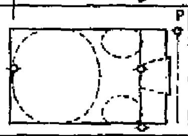
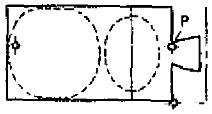
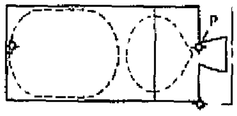
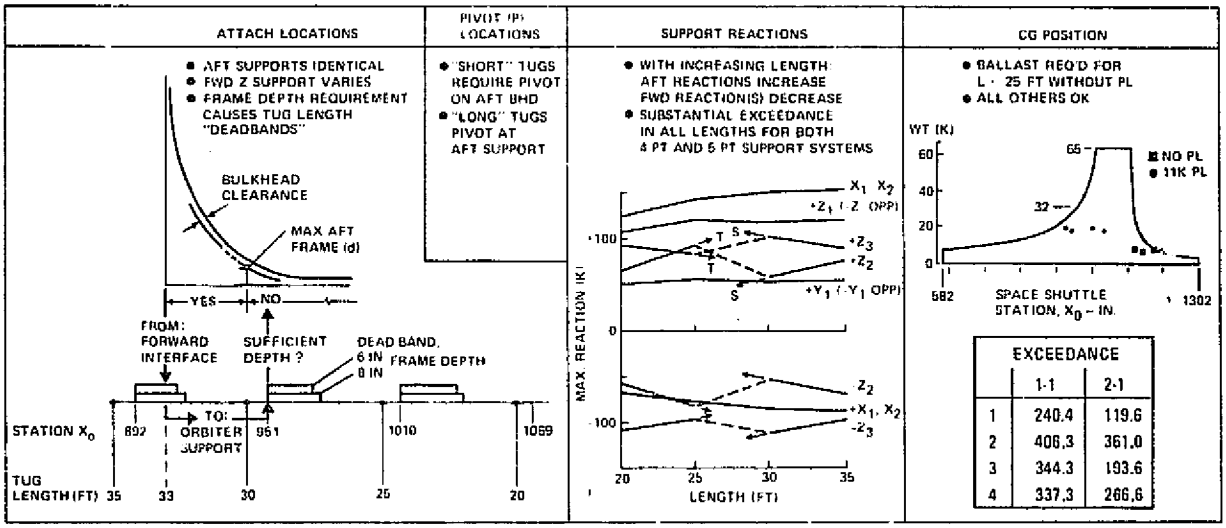
CONFIGURATION		CHARACTERISTICS								
NO.	X_0 = 892, 951, 1010, 1069, 1246, 1302	LENGTH FT	LENGTH M	PIVOT AXIS (P) X_0/Z_0	ASCENT MASS PROPERTIES: MISSION TYPE	WEIGHT LB	WEIGHT KG	CG STA, X_0	OXIDIZER TANK CONFIG.	MIXTURE RATIO O/F
1	P 	20.0	6.1	1302/490	DEPLOY RETRIEVE	56966 45966	25863 20869	1149.68 1205.36	TOROID	6.5/1
2	P 	25.0	7.6	1302/490	DEPLOY RETRIEVE	64612 64612	29334 29334	1143.21 1197.06	TOROID	6.5/1
3	P 	30.5	9.3	1246/414	DEPLOY RETRIEVE	63808 57487	28969 26099	1088.88 1147.58	SPHEROID	6.0/1
4	P 	34.5	10.5	1246/414	DEPLOY RETRIEVE	64659 64659	29355 29355	1083.49 1147.43	SPHEROID	5.4/1

Figure 5.7-1. Characteristics of Reference Configurations

Configuration 4 was the Convair STSS Program 2 vehicle. Configuration 3 was the study reference configuration (Section 4.2.1.1). Configuration 2 was a point design developed during Convair inhouse short-Tug studies, and Configuration 1 was a still shorter derivative of 2.

The various effects of Tug length variation are presented in Figure 5.7-2. As shown certain Tug lengths were not permissible if support locations were limited to those



	EXCEEDANCE	
	1-1	2-1
1	240.4	119.6
2	406.3	361.0
3	344.3	193.6
4	337.3	266.6

Figure 5.7-2. Effects of Tug Length Variation

currently provided by the Orbiter. This situation resulted from limits on acceptable locations of the forward interface frame within the Tug structural system. Typically, a 6 to 8 in. (15.2 to 20.3 cm) deep interface frame was required for distributing support fitting loads into the Tug shell. Tug frame alignment had to coincide with an Orbiter attachment station, but frame location relative to the Tug forward interface was constrained by the fuel tank forward bulkhead. The possibility of additional limits on forward support frame location due to avionics package size and mounting requirements was also investigated, but it was found that mounting requirements for currently defined Tug avionics packages did not further constrain interface frame location. The resulting Tug lengths precluded by the bulkhead clearance constraint are indicated as deadbands.

Because of the deploy adapter aft extension in the two short Tug configurations, the pivot had to be placed near X_0 1302/Z_0 490 to avoid violation of the cargo bay envelope by the adapter during rotation. Since the adapter terminated at the aft support station in the two long-Tug configurations, the pivot could be incorporated into the aft support fittings (at X_0 1246/Z_0 414) without clearance envelope violation caused by rotation.

Support reactions and the resulting accumulated exceedance of Orbiter capability were computed for two support arrangements (1-1 and 2-1, Section 4.2.2.1) for each of the

reference Tugs. The computations used cargo bay accelerations from MSFC 68M00039-1 and employed the computer program and exceedance computation method discussed in Section 4.2.2.2. The resulting reaction trends as a function of Tug length are shown for support arrangement 1-1. Arrows indicate trend directions for spheroidal, S, and toroidal, T, oxidizer tank configurations. As noted within a given oxidizer tank configuration family, the aft reactions increased and forward reactions decreased with increasing vehicle length.

The trends were similar for support arrangement 2-1, but individual reactions differed in magnitude. Comparing the accumulated exceedance, a trend toward increasing exceedance with increasing length, within oxidizer tank families, was found except in the spheroidal tank (long Tugs) using support arrangement 1-1, where little variation occurred. Support arrangement 2-1 exhibited an advantage over 1-1 in all Tug lengths.

The reduced-length high-performance Tugs employed toroidal oxidizer tanks to provide increased propellant packaging efficiency over the reference Tug and therefore exhibited a further-aft cg. As shown, the only Tug penalty imposed by the Orbiter cg limit was a ballast requirement for lengths less than 25 ft (7.6 m) when returning without a spacecraft (i.e., nominal descent from a deployment mission or abort descent from a retrieval mission, assuming dump of both propellants).

5.8 SENSITIVITY ANALYSES SUMMARY

No major revisions to the subsystem analyses results of Task 2 (Section 4) were recommended due to the sensitivity analyses. In several areas, however, minor revisions were recommended to render Tug/payload/Orbiter interfaces more amenable to potential revisions.

Where appropriate, results from these seven sensitivities that served to desensitize Tug interface requirements were integrated into the Task 2 interface recommendations discussed in Section 4. A summary of significant results and data obtained from these sensitivity studies is contained in Figure 5.8-1 and the following text.

Two of the seven sensitivity studies indicated major potential Tug/Orbiter interface impact — fluid services and Tug length. No compromise solution appeared feasible to desensitize the incorporation of a Tug with storable main propellants or significant length revisions. If Tug revisions of this type do occur, major changes in Orbiter and Tug peripheral equipment and fluid interface kits will be required. The overall result of the sensitivity analysis task is that no major Tug/Orbiter interface revisions to the recommendations of Task 2 are needed or desirable.

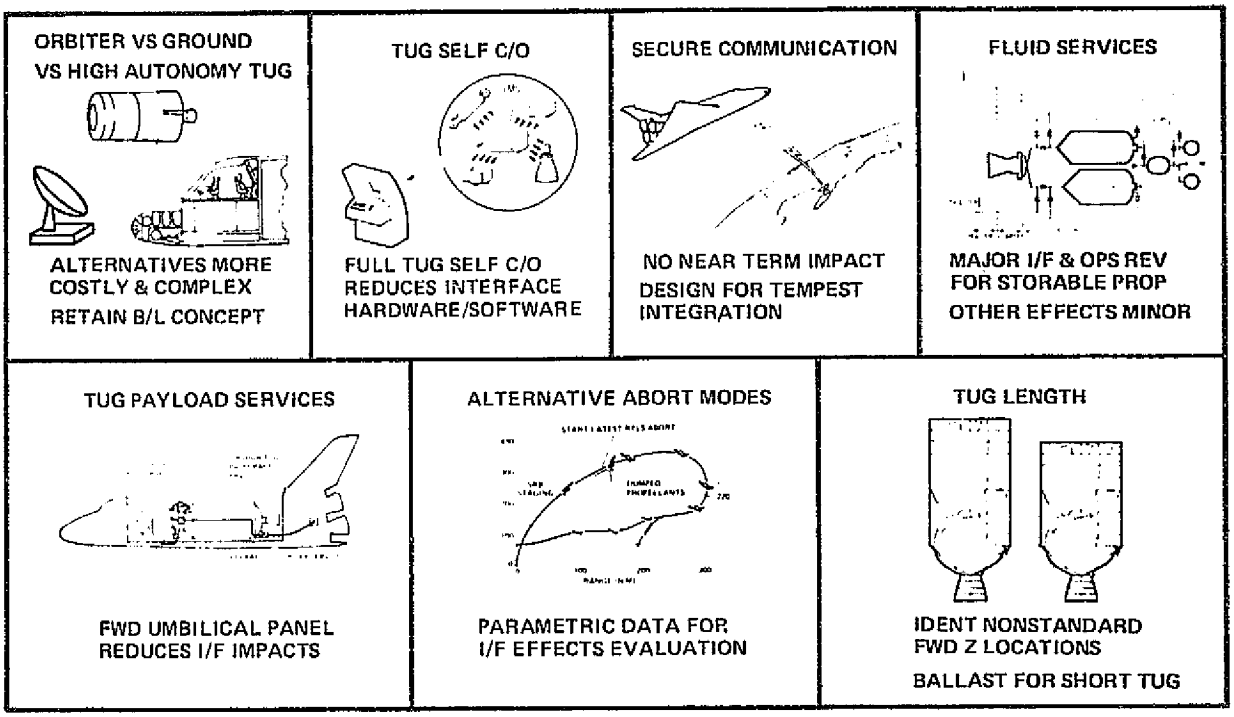


Figure 5.8-1. Sensitivity Investigation Results